## 9. INSTRUMENTS AND TECHNIQUES

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### INTRODUCTION

It is clearly impossible to prepare a comprehensive review of three years' work in the field of astronomical instrumentation within the space available in this volume. The selection of topics included and the space devoted to each is therefore largely subjective; some emphasis has been placed on material unlikely to be generally available elsewhere.

### LARGE TELESCOPES

A conference on "Optical Telescopes of the Future" was held in Geneva in December 1977 and the proceedings (eds. F. Pacini, W. Richter and R.N. Wilson, ESO, Geneva, 1978) contain detailed accounts of the state of many large telescope projects and design studies up to that time. It is clear that many new ideas in telescope design are being conceived or applied in new projects; the current state of some of the more significant projects is given below.

During the period 1976-1978 regular observations began with the U.S.S.R. 6.0 metre telescope (BTA). Its limiting photographic magnitude is $24.5^m$, accuracy of pointing to a star ±10". In the primary focus a fast spectrograph with electro-optical image sensors is used. The spectrograph has two optical cameras: a Schmidt -Cassegrain with a focal ratio of 1:1 (f=100mm, $\Delta\lambda$ 0.3-0.7 μm and 0.7-1.2 μm) and a Maksutov-Cassegrain 1:2 (f=200 mm, $\Delta\lambda$ 0.35-0.7, 0.7-1.2 μm). The spectrograph is equipped with two diffraction gratings providing for dispersions from 60 to 370Å/mm.

More than 400 spectrograms have been taken with the spectrograph. More than 150 large-scale photographs of interacting pairs and groups of galaxies have also been obtained. From spectrograms of the 150 pairs of double and interacting galaxies their dynamic masses have been determined and the absence of hidden mass in the galaxies has been shown.

Experimental observations using speckle interferometry have been made by the Astronomical Observatory of the Kharkov State University with the 6.0 metre reflector (Dudinov V.N. et al., Vestnik Khark.Univers., 1977, No.160, pp.76-86). The angular diameter of the star α Boo was measured and proved equal to $0''.018 \pm 0''.004$.

A Zeeman analyzer of circular polarization and photoelectric star magnetograph with a Fabry-Perot interferometer were made for the main stellar spectrograph. The measurement accuracy of the magnetic field is ±20 G, spectral resolution 0.08 Å. Digital systems of speed photometry and speed spectroscopy were designed and built.

Great attention was paid to improvement of methods for testing astronomical optics (Korovikovsky Yu.P., Shabanov M.F., Optiko-Mekh. Prom., 1977, No.12, p.3; Zverev V.A. et al., ibid, 1976, No.12, p.6, Zverev V.A. et al., ibid, 1977, No.3, p.3; Kirillovsky V.K. et al., ibid, 1976, No.8, p.14). A mathematical model has been built describing the variation of the BTA focal plane position in dependence on the temperature variation.



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At Mauna Kea Observatory (Hawaii) three interesting new telescopes are nearing completion. The U.K. Infrared telescope, which is now in partial use, is the first to use the thin-mirror concept and the project has proved that 1 arcsec images can be obtained with a 3.8 m diameter mirror only 0.25 m thick. The 3.8 m C.F.H. Telescope, although mainly of classical design, incorporates a high-efficiency coudé system and comprehensive computer control of both telescope and instruments. It should be able to take full advantage of the fine seeing which is often available at Mauna Kea. The 3.0 m U.S. infrared telescope will be the first to have such accurate control of pointing and tracking as to enable it easily to find and follow objects in daytime. Consideration is being given to linking the coudé foci of the U.K. and C.F.H. telescopes, which are separated by $\sim$ 300 m, to enable the C.F.H.T. coudé spectrograph to be used with either telescope separately or with the combined beams of both. It is conceivable that the two telescopes may be used as an angular interferometer.

The Multiple-mirror telescope at the Mt. Hopkins Observatory in Arizona will be dedicated in 1979; it has shown that large telescopes can be successfully constructed from smaller mirrors actively controlled to yield a single image, and contains other innovations in its altazimuth mounting and rotating building.

The U.S. project to study possible designs for a very large ground-based telescope has resulted so far in a number of interesting reports of the various systems under consideration. The U.K. Northern Hemisphere Observatory project team has completed the design of a 4.2 m altazimuth optical telescope. I.N.A.G. has constructed a 2 m telescope at the Pic-du-Midi Observatory which will be completed in 1979. It has a special dome designed to eliminate thermal effects, to ensure very high spatial resolution. It will be used in the visible and infrared with computer control of the telescope and instruments.

Work has continued in NASA and in E.S.A. on the design and construction of the 2.4 m Space Telescope and its instruments, to be launched in 1983. The first set of focal-plane instruments to undergo detailed design studies comprises a wide-field camera, a faint-object camera, a faint-object spectrograph, a high-resolution spectrograph and a high-speed polarimetric photometer.

Work continues at the Indian Institute of Astrophysics on the 2.34 m reflector for Kavalur. The detailed engineering designs for the mounting are now complete and the dome and building will be ready by August 1979. The telescope will have an f/3.25 paraboloid primary, f/13 cassegrain and f/46 coudé foci.

## PHOTO-ELECTRONIC IMAGE DEVICES
(Report by the Chairman of the Working Group, Dr M.F. Walker)

### I. Introduction

It is with deep regret that we note the death of Prof. A. Lallemand on March 24, 1978. He was the first to undertake the development of a practical image tube for use in astronomy, and his pioneering results provided the impetus of the present development and use of photoelectronic detectors in astronomical research. His continuing interest in this field and his counsel on the technical problems of detectors will be greatly missed.

The following report, like the preceding one published in Trans. IAU XVIa, has been prepared mainly from replies received to a circular letter sent to all members of Commission 9 and to the Directors of Observatories and Astronomical Institutes, and is intended primarily to reflect the status of work currently in progress.

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## II. Conferences

Two conferences on photoelectronic image devices and their application in astronomy were held during the period since the last report:

1) I.A.U. Colloquium No.40, "Astronomical Applications of Image Detectors with Linear Response", Observatoire de Paris-Meudon, Meudon, September 6-8, 1976. The proceedings, edited by M. Duchesne and G. Lelièvre, have been published by the Paris-Meudon Observatory.

2) The "Seventh Symposium on Photoelectronic Image Devices", Imperial College, London, September 4-8, 1978. Preprints of the papers presented at this Symposium have been published by Dr B.L. Morgan, Blackett Laboratory, Imperial College, London, and are available at a cost of £12. Approximately half of the papers contained in this volume will be published at a later date by the Academic Press in their series Advances in Electronics and Electron Physics.

Limitations of space make it impractical to cite individual literature references in this report. However, developments discussed at the two foregoing conferences are so indicated, "Ref.1" referring to I.A.U. Colloquium No.40 and "Ref.2" to the Imperial College Symposium.

## III. Electronography

a) Developmental Work. Developmental work on electronographic image tubes was carried on in Paris, Meudon, Herstmonceux, Austin, and the U.S.S.R. during the report period. At the Paris Observatory, work was carried out on the development of an electrostatically-focussed electronic camera having a field 40 mm in diameter by Duchesne and his collaborators. In addition, Duchesne has studied the problems posed by the use of S-1 and S-20 photocathodes in electronic cameras of the Lallemand-Duchesne type. At Meudon, development work has continued on the two types of electronic cameras described in previous reports: an electrostatically-focussed camera and a magnetically-focussed camera using a strong magnetic field produced by a superconducting magnet. Both systems are equipped with valves between the photocathode and recording emulsion to protect the cathode while changing the nuclear plates. At present, effort is concentrated on the electrostically -focussed camera for use at the prime focus of the C.F.H. telescope in Hawaii. This camera will have a photocathode 30 mm in diameter and a magnification of unity. Details of these cameras are given in Ref.1.

At the Royal Greenwich Observatory, Herstmonceux, development of the large-field magnetically-focussed electronic cameras has been continued by McMullan and his co-workers. During the report period, effort has been concentrated on improvement of technical details of the cameras, such as the method of film application and contacting to the mica window, supplying cameras to other observatories and the development of a larger-window camera. This latter camera has a cathode diameter of 85 mm, compared to 40 mm diameter in the first model, and a prototype of this system has been constructed and operated successfully. Cameras with 40 mm fields are now in operation at the Wise Observatory, Israel, the Sutherland Observatory, South Africa, the Anglo-Australian Observatory, and a camera has been constructed for use on the Danish 1.5 m telescope at La Silla. A 40 mm field camera has been used for two successful observing runs on the 2.2 m telescope at Mauna Kea, and a more compact model of the camera has been built to facilitate transporting the system to remote locations for short observing runs. Additonal details are given in Refs. 1 and 2.

In Austin, Griboval has successfully tested the Mark II electronic camera on the 0.76 m telescope of the McDonald Observatory, where direct exposures of up to 70 min on Kodak Electron Image Film were obtained (Ref.2). This camera has a 50 mm diameter field and a resolution equal to the optical resolution in 1" seeing when used on a telescope of 10 m focal length.

In the U.S.S.R., a Spectracon-type electronographic image tube has been developed at the All-Union Scientific Research Institute of Optical and Physical Measurements, under the direction of Prof. Butslov. This tube has a field of 3 x 30 mm, a resolution of 60 lp/mm, and a dark current set by the thermionic emission of the photocathode at room temperature. The system has been used in astronomical spectroscopy to record very faint absorption lines (equivalent width ≈ 2 mÅ) (Ref.1).

b) Use in ground-based astronomy. The Lallemand electronic camera has continued to be used for the types of observations discussed in the preceding report. These include: Spectroscopic observations of the Ca II K Line profile in A stars at high resolution (Felenbok), direct electronographic observations of planetary nebulae in the near infrared for morphological studies (Andrillat and Duchesne), direct observations of BL Lac objects and N Galaxies (Wlérick and Lelièvre), direct observations of the structure of the core of M 15 (Auriere, Laques and Leroy), for two-dimensional photometry of the Orion Nebula and comet Kohoutek (Despiau, Laques and Vidal), and spectroscopic observations of short-period variable stars (Lecontel). In addition, the large-field magnetically-focussed Lallemand camera has been used on the 1.93 m reflector at Haute Provence for direct electronographic studies of a number of different types of extra-galactic objects (Wlérick, Lelièvre, Servan, Renard and Lefèvre) (Refs. 1 and 2).

The Kron camera has been used at Flagstaff for a number of programs. These include: A study by Ables of the globular clusters around M 87 using a computer program for stellar photometry developed by Hewitt. With this program, microphotometer data are analysed on the basis of signal-to-noise ratio to discriminate against plate defects and nearby star images and to minimize errors in the presence of sky background. Hewitt, Ables and Vrba have developed a system for using bright, primary UBV standards to determine the colour-equation of the Kron camera; the photocurrent is measured with a silicon photodiode which is introduced into the camera in place of the usual electronographic emulsion. Ables and Dahn are continuing photoelectric and electronographic UBV photometry of stars in six areas equally spaced around the sky at approximately +35° declination, to establish UBV standards from $11 \leq V \leq 22$ in uncrowded fields 7' in diameter for use with panoramic detectors. Hewitt is using the Kron camera to measure separations and magnitude differences between components of double stars between 1".8 and 6" separation, while Thomsen and Ables are using electronographic exposures in an attempt to determine the separation and magnitude difference for the Pluto-Charon system. At Mount Hopkins, the Kron camera continues to be used as the detector with the Cassegrain echelle spectrograph of the 1.5 m telescope. Dunham is studying the information acquisition rate of the Kron camera and of Kodak IIIaJ emulsion when used with this spectrograph. At Kitt Peak, the Kron camera was used by Gull to obtain direct electrographs of the Orion Nebula in the light of Hβ and adjacent continuum to study the variation of the continuum/Hβ ratio and the polarization of the continuum throughout the nebula (Ref.1).

Spectracons continue to be used at a number of observatories. At Lick, Walker has continued to use the Spectracon with the Bowen f/1 camera of the 120-inch coudé spectrograph to obtain spectra at 115 Å/mm of rapid variable stars, T Tau-type stars, and pre-main sequence stars in the Orion Nebula cluster and NGC 2264. Morgan, Hardwick and Harrison have used the Spectracon to obtain UBV observations of the elliptical galaxies NGC 4881 and NGC 3379 with the 1.5 m telescope of the U.S. Naval Observatory, Flagstaff and the 1.9 m Helwan Observatory reflector. A second program of six-colour observations of nearby elliptical galaxies to study the variation of stellar population with radius has been carried out by Morgan, Baum and Thomsen using Spectracons at the Cassegrain focus of the 1.8 m Perkins reflector at the Lowell Observatory, Flagstaff. Baum and Thomsen have used the

Perkins telescope and a Spectracon to determine the albedo of the rings of Uranus. A second attempt to detect the rings was made by Baum, Wilkinson and Loh using the same telescope and a CCD detector. Although no rings were visually evident in either set of images, computer processing of the images appears to indicate detection and to imply an albedo of 0.02 for the rings; the rings are thus black, whereas those of Saturn are relatively white. A program of electronographic UBV photometry of close visual double stars has been carried out by Penny using a Spectracon at the f/18 Cassegrain focus of the 0.5 m telescope of the Sutherland Observatory.

A McMullan electronographic camera has been in routine use for direct observations at the Cassegrain focus of the 1.0 m reflector at Sutherland. Stellar photometry on the UBV and DDO systems has been carried out for stars in the Galaxy and in the Magellanic Clouds. In addition, observations have been made of the structure of nearby quasars and peculiar galaxies. The camera has also been used for polarimetric observations. McMullan cameras have been used by Penny at Herstmonceux, Sutherland, Mauna Kea, and on the Anglo-Australian Telescope for stellar photometry and pulsar work. Penny, McMullan, and other workers at Herstmonceux have developed phase-resolving deflection coils and electronics for the McMullan camera to permit its use on pulsars, and a dichromic beamsplitter to enable simultaneous electrographs to be taken in two colours, for use in BV observations of clusters.

c) Use in space astronomy. The application of electronography in space astronomy by Carruthers and his co-workers, discussed in the preceding report, has continued. Work prior to September, 1976, is discussed or referenced by Carruthers in Ref.1. Since that date, discussion of data obtained during the Apollo 16 flight has continued and includes studies of far-ultraviolet spectra in the Large Magellanic Cloud (Carruthers and Page) and the S201 Far-Ultraviolet Atlas of the Large Magellanic Cloud (Page and Carruthers, NRL Report 8206, 1978). Discussion of data obtained during sounding rocket flights has also continued and papers have been published on Carbon and Oxygen Production Rates for Comet Kohoutek (Opal and Carruthers), Lyman-Alpha Observations of Comet West (Opal and Carruthers), Rocket Ultraviolet Imagery of the Andromeda Galaxy (Carruthers, Heckathorn and Opal), Far-Ultraviolet Imagery of the Orion Nebula (Carruthers and Opal), a Far-Ultraviolet Spectrographic Survey of some Orion Stars (Carruthers, Opal and Heckathorn). In addition, a new electronographic camera of the semi-transparent photocathode, magnetically-focussed type, having an image format 123 mm in diameter, has been built and tested. This camera is intended for possible use with astronomical telescopes to be flown in Shuttle-Spacelab missions in the 1980's. The present laboratory prototype is sensitive below 2000Å using conventional or mesh-based semi-transparent alkali-halide photocathodes. With a flat photocathode, resolution better than 100 lp/mm is maintained over the entire 123 mm format. It has been demonstrated that this resolution can be retained over the entire format with a curved photocathode (500 mm convex radius) by the use of a magnetic field in excess of 5000 Gauss, produced by a superconducting magnet. Development is now underway of a version of this camera sensitive to the middle ultraviolet (2000 - 3000Å) by the use of a cesium telluride photocathode and a Griboval-type barrier membrane. It is hoped in the near future to increase the format size to 200 mm and to extend the wavelength coverage to the near ultraviolet and visible (Ref.2).

d) Reduction of electronographic observations. Development of optimum methods for the reduction of electronographic observations continues to be a matter of great importance. A review of these reduction methods has been given by Pilkington (Ref.1) and new techniques have been described by Hardwick and by Hewitt (Ref.2).

## IV. Image Intensifiers

Image intensifier tubes continue to be widely used in astronomy. New applic-

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ations during the present report period include:

At the Steward Observatory, a number of image tube detectors have been developed for use with the 2.2 m telescope. These include:

1) An RCD C33063 38 mm two-stage magnetic intensifier having a specially selected photocathode for the spectral region from 3000 - 6000Å, and having a specially designed short-overhang permanent magnet array which provides compatibility with optical cameras for both the Cassegrain and echelle spectrographs. For spectroscopic application, a special mask and plate-trailing mechanical assembly is provided for this and other image tube systems.

2) A three-stage Varo 40 mm electrostatic intensifier for the recording of spectroscopic and speckle interferometry images.

3) A three-stage Varo 40 mm "booster" system with a special magnetic shield enabling it to be placed behind the RCA magnetic tube described in (1) above. This system increases the gain of the magnetic tube for application of various solid-state arrays as readout systems.

4) A four-stage Varo 40 mm intensifier with a first photocathode selected to cover the range from 5000 - 9000Å, for use with the Cassegrain and echelle spectrographs and for speckle interferometry.

5) An ITT F4089 40 mm single-stage magnetically-focussed tube used primarily for direct photography.

6) An ITT F4094 146 mm single-stage magnetically-focussed tube used for direct photography and the infrared survey of the northern sky presently underway at the Observatory. This survey will cover the entire sky north of the celestial equator in two colours: an infrared band from 8000 - 9000Å and the visible V band. Exposures of 5 min in the visible and 15 min in the infrared with the modified 0.5 m Baker reflector-corrector telescope give limiting magnitudes of V = 15 and I = 17.5. The scale is 110"/mm and the resolution about 33 lp/mm, due to the photographic emulsion (Kodak IIaD) used to record the images).

7) A three-stage Varo intensifier plus storage vidicon system for field acquisition and guiding (Ref.2).

At Imperial College, a speckle interferometer has been designed and constructed which uses an EMI four-stage intensifier to enable short ($\sim$ 0.01 sec) exposures of stellar images to be recorded on 16 mm cine film. This system has been used by Beddoes, Morgan, Scaddan and Dainty with the 2.5 m Isaac Newton reflector at Herstmonceux, and the 1.9 m reflectors of the Haute Provence, Kottamia and South African Observatories, to observe variable stars, visual binaries and spectroscopic binaries. A list of binary star separations and position angles has been published.

In South Africa, a three-stage E.M.I. image intensifier with output recorded on Kodak IIaO plates is in routine use on the Cassegrain spectrograph of the 1.88 m Sutherland reflector.

At the Kavalur station of the Indian Institute of Astrophysics, Bangalore, a Varo 8605 intensifier is used for direct photography of the central regions of Sersic galaxies at the Cassegrain focus of the 1.02 m reflector. The same system is also used as the detector with the Cassegrain spectrograph of the 1.02 m telescope for spectroscopic observations of the central regions of these galaxies, at dispersions ranging from 30 - 600 A/mm. An echelle spectrograph also using a Varo 8605 image intensifier as the detector has undergone final tests at the coudé focus of the 1.02 m telescope. Another detector system, employing an image con-

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verter tube developed at the Bhabha Atomic Research Centre, Bombay, has been employed at the coudé focus of the 1.02 m telescope for a survey of the profiles of the D3 lines in the spectra of late-type stars. At the Centre for Advanced Study in Astronomy, Usmania University, Hyderabad, a Varo 8605 40 mm single-stage intensifier is on order for use with the Meinel spectrograph on the 1.2 m telescope of the Rangapur-Japal Observatory and for prime focus photography.

At Kitt Peak, two and three-stage 40 mm cascade intensifiers are routinely used for limit spectroscopy and narrow band direct work. The very large 80 to 160 mm optic tubes that once seemed so promising have been abandoned because of fixed pattern noise and the superior properties of new photographic emulsions.

In the U.S.S.R., the M9 Shch V image tube is used with the SP-160 spectrograph of the 6 m reflector. This tube, developed at the Institute of Optical and Physical Measurements from technical specifications set down by Rylov at the Special Astrophysical Observatory, is a single-stage magnetically-focussed intensifier with a 25 mm field and a fibre optic exit window. The resolution is 50 - 55 lp/mm and the multialkali photocathode has a sensitivity range from 3500 - 8000Å with a quantum efficiency of 12 - 20% in the 4000 - 5500Å range. The working voltage is 15 - 20 KV, and the maximum exposure with a photocathode temperature of 20°C is one hour. The gain of these tubes over A-500 or Kodak 103aO emulsion is 20 - 40 in the 4000 - 5000Å range. On the 6 m telescope, the spectrum of a 16.7 magnitude star is recorded in one hour at a dispersion of 70 Å/mm from 3600 - 5200Å with an image size of 2" and a slit width of 1".

## V. Electrical Output Detectors

a) Television type systems. At Princeton, Lowrance is continuing development of the 70 mm SEC system for the space telescope and a similar system for ground-based astronomical applications (Ref.1). An SEC vidicon system for observations of ultraviolet stellar spectra with the NASA Balloon-borne Ultraviolet Spectrograph has been developed by Hoekstra at Utrecht, and used on two successful flights in 1976. Used with an echelle spectrograph, spectra from 2000 - 3400Å with a resolution of 0.01Å were obtained for 33 stars with types from O9.5 - M2. At Ondrejov, Valnicek is pursuing the development of an SEC system and of a system using a vidicon with CdSe target-chalcogenic glass in combination with storage tube and silicon target. A system consisting of an ITT-type F4122 ultraviolet-to-visible image converter fibre-optically coupled to a Westinghouse-type WX32224 SEC camera is being used as the detector system on the International Ultraviolet Explorer satellite, and has been in routine operation since April 3, 1978 (Ref.2).

The use of S-T and SIT vidicons for astronomical observations has been reviewed by Westphal and Kristian (Ref.1). At Tololo, an integrating SIT system has been developed by Ingerson, Lasker and Osmer for spectroscopic applications (Ref.1). An ultraviolet-sensitive SIT tube has now been obtained for this system and has been in use for one year for observations from the atmospheric cutoff to beyond Hα. With completion of a new spectrographic camera and coldbox, resolutions of 40 - 50 microns and positional measures to 5 - 10 microns are expected. The system noise per element at the telescope is equivalent to two detected photons, so that photon-noise-limited performance is achieved in nearly all applications. The system has been operated at very low light levels: Osmer has observed spectra of quasars somewhat fainter than magnitude 21 and Lasker has detected very weak emission lines in supernova remnants and galaxies. The absence of counting rate limitations and afterglow problems is a distinct advantage. An ISIT video camera is regularly employed at the Cassegrain foci of the 2 and 4 m Kitt Peak telescopes. This system gives a 256x256 pixel array, quantum limited from 4000 - 8500Å. Stellar objects of V = 23 may be recorded in 13 min. The Palomar Sky survey limit is attained in ∿ 30 min for a bandwidth of 70Å at Hα in continuum-type objects. Integrating vidicon and SIT vidicon systems for two-dimensional sky-limited photometry

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have been developed by Mackay at Cambridge. Laboratory tests suggest that a photometric accuracy of better than 0.5% should be achievable over a 1" image at the prime focus of a large telescope. A 40 mm input SIT camera with an S-1 first photocathode has been constructed by Gow, Sandford, Honeycutt and Jekowski at Los Alamos and used for direct observations of stars in the R, I and J photometric bands. The system is cooled with dry ice to -40°C and has a resolution of ∿ 15 lp/mm. Photometric accuracy of ≲ 0.1 mag over a range of 5 - 6 magnitudes appears possible (Ref.1). An ISIT system for field acquisition has been developed at the Steward Observatory.

The image photon counting system developed by Boksenberg at University College London has continued to be used for observations of the spectra of normal and peculiar galaxies and QSOs with the Palomar 5 m telescope, and a ruggedized version for use with the space telescope is being developed by Boksenberg and Coleman (Ref.1). At Marseille, Boulesteix and Cenalmor have developed an image photon system consisting of a microchannel plate electrostatic intensifier (Thompson CSF-TH 9303) coupled by fibre optics to a SIT camera (Thompson CSF-TH 9655). The detection logic gives a 256x256 grid, each pixel being 55 microns on the photocathode. The resolution is 9 lp/mm, the dark noise 2 events / pixel / hour and the response is linear from 2 - 3000 events / pixel / hour (Ref. 1,2). Also at Marseille, Lamy, N'Guyen-Trong and Perrin have developed a detector system using a television camera equipped with a tube whose response extends to 2.4 microns.

At Lick Observatory, the Robinson-Wampler image dissector scanner has been upgraded to record up to 32,768 channels that can be organized in any number of separate lines from 2 to 64. This new system has been used mainly to record simultaneous spectra from 8 slits across an extended object (Ref.2). It has also been used in the 64 scan mode to record direct images. Direct imaging with the image dissector scanner at the McDonald Observatory has also been reported by Rybski, Van Citters and Bennedict, who obtained shot-noise-limited performance and linear response from 17.2 - 23.4 magnitudes/arcsecond$^2$ (Ref.1).

b) Diode Array Detectors. Progress in the use of diode arrays in astronomical research to September, 1976, has been reviewed by Livingston (Ref.1). As discussed in the previous Report, diode arrays are sensitive to both electrons and photons and have many advantages as detectors. Their major drawback continues to be their high detector noise when used as photon detectors, limiting their application to high light levels. Consequently, for low light level application diode arrays continue to be used either as photoelectron detectors behind a photocathode, as in the self-scanned Digicon, or as photon detectors following an image intensifier. Recent developments in the first type of device include: (1) Manufacturing of new dual-array self-scanned Digicons by Electronic Vision Company using Reticon arrays consisting of two parallel arrays of 936 elements each on a single integrated circuit chip; the diodes are on 30 micron centres 375 microns long, and with no dead space between diodes or between arrays. Digicons of this type are in use at McDonald for Cassegrain spectroscopy on the 2.1 m reflector, and have been purchased by the University of Western Ontario, Asiago Observatory, and the Wise Observatory. (2) Development by Johnson and Williams at ITT and NASA and by Lowrance, Zucchino and Renda at Princeton of systems having an opaque-cathode, oblique magnetically-focussed electron optics, and a CCD to detect the photoelectrons, for use in the extreme ultraviolet (Ref.2). (3) A 512 channel Digicon is being constructed for use as the detector for all spectroscopic measurements on the space telescope (Ref.2).

New systems of the second type include: (1) a pulse counting linear array detector for spectroscopy developed at Kitt Peak, consisting of an 18 mm proximity-focussed ITT fibre optic tube coupled to a Varo microchannel plate plus a Reticon 2x936 element array. (2) An assembly of six tandem 40 mm fibre optic coupled image tubes plus a Reticon dual 1024 element array at Mount Stromlo (Ref.2).

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(3) An EMI 9914 four-stage intensifier optically coupled to a 1024 element Reticon at the Max-Planck-Institute (Ref.2). (4) A three-stage tube plus Reticon 2x936 array at Mount Hopkins (Ref.2).

Notwithstanding the high noise level of diode arrays when used as photon detectors, practically all research and development effort at Kitt Peak by the panoramic detector group headed by Lynds is presently directed toward their utilization in this mode. Two "visitor-qualified" CID cameras using GE 100x100 arrays have been built for high light level applications such as high-resolution spectroscopy of bright stars, solar spectroscopy, and narrow-band planetary imagery. In addition, a 190x244 Fairchild 211 CCD is being tested at the prime focus of the 4 m telescope, while a linear 1728 element Fairchild array is being investigated for high-dispersion coudé spectroscopy and a 32x32 element InSb CID is being tested for infrared applications in the 1 - 5 micron region. Paralleling these detector developments, an equal amount of research at Kitt Peak is being directed toward the problem of processing and reducing the data from array detector systems. At McDonald, the Tull-Nather low-dispersion Reticon spectrograph has been improved. Resolution is 40Å, the 256 element array covering 5500Å simultaneously within the working limits of 4000 - 11,000Å. The detective quantum efficiency is up to 40% for a well-exposed spectrum, and response is linear. Internal spectro-photometric accuracy is better than 0.5%. In addition, a liquid nitrogen-cooled Reticon with 1024 elements is used at the coudé spectrograph of the 2.7 m telescope. High precision can be obtained at high dispersion with stars to $\underline{V}$ = 10 - 14, depending on colour and dispersion. Further, a Reticon with 1728 elements on 15 micron centres is being readied for installation in the coudé spectrograph of the 2.1 m telescope. At the University of British Columbia, a 50x50 Reticon array and a 400x400 Texas Instruments array have been used for broad-band imagery of galaxies and narrow-band studies of emission nebulae (Ref.2).

c) Microchannel detectors. The characteristics of microchannel plates and their applications to photon-counting image systems to September 1976 are reviewed by Lampton and by Timothy (Ref.1). Since that time, effort has been concentrated on the development of image intensifiers using microchannel plates and output phosphors. Photon counting systems utilizing image tubes of this type have been developed by Rosier and Polaert, Laboratory of Applied Electronics and Physics, Brevannes, and N'Guyen-Trong and Sidoruk, Laboratory of Space Astronomy, Marseille (Ref.2), and by Airey, Morgan and Ring, Imperial College, London (Ref.2).

## PHOTOGRAPHIC TECHNIQUES

(Report by the Chairman of the Working group, Dr R.M. West)

The Proceedings of the IAU WG meeting in Grenoble, August 1976, have been published (Ed. : J.-L. Heudier, October 1976). A Bibliography on Astronomical Photography was compiled by M.E. Sim (September 1977). A workshop on "Modern Techniques in Astronomical Photography" was organized by the European Southern Observatory under the auspices of the IAU WG in May 1978; the Proceedings were published by ESO (300 p., eds. : R.M. West and J.-L. Heudier).

The AAS Photobulletin now appears regularly with three issues per year. The WG recommends that papers related to astronomical photography be published in this journal. A very comprehensive Darkroom Manual has been written by Wm. C. Miller.

The WG Organizing Committee met in Geneva, Switzerland, in May 1978. The WG membership list now comprises about 350 addresses in about 40 countries.

The past three years have seen a consolidation of the hypersensitization techniques. Most blue and red emulsions are efficiently treated by baking in forming gas ($N_2$ + 2-10% $H_2$). Bathing in $AgNO_3$ gives excellent and consistent results for infrared emulsions. A detailed summary of the various techniques is given

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by A. Millikan (AAS Photobulletin, 1978, 18, 10). Accurate calibration of photographic plates is becoming more usual at the observatories; it is noted that, for comparison, the exposure should be expressed in (photons 1000 $\mu m^{-2}$; with specified time and effective wavelength). Sets of "Interobservatory Densitometer Plates" made by Kodak and the AAS Working Group on Photographic Materials have been circulated to many observatories in order to provide calibrations to the standard density scale (ANSI diffuse).

There is an increased interest in colour work; due to the low efficiency of most colour emulsions, it appears that superposition of three b/w photos (digitally, by direct printing or by dye transfer) holds a greater promise.

With the abolition (in 1972) of certain export restrictions on photographic materials from Kodak, astronomically useful emulsions are now universally available. However, some observatories still encounter problems with excessive transit times, often because of delays in customs. The IAU WG expects to draw up a set of guidelines for transport of unexposed and exposed plates, in order to help overcome these difficulties.

DATA REDUCTION

(Report by the Secretary of the Informal Working Group, Dr C.T. Bolton)

At the Grenoble General Assembly of the International Astronomical Union in August, 1976, Ivan King organized a small, informal meeting of PDS microdensitometer users in order to exchange information on hardware and software problems and experiences. Attendance at this meeting was much larger than had been anticipated, and it quickly became apparent that there was a need for a formal organization to promote exchange of information on both hardware and software used in astronomical image processing. An organizing committee, consisting of Ivan King, C.T. Bolton, David Latham and M. Schneider was appointed from the group at this meeting.

The Working Group undertook the publication of Circulars containing informal communications on Computer Processing of Astronomical Data. Three of these were sent to a mailing list of approximately 100 scientists during the report period. In addition the Working Group undertook a literature and mail survey aimed at compiling a Catalog of Astronomical Image Processing Facilities. This Catalog was published in the Circulars and in the Bulletin of the American Astronomical Society (Bolton, C.T. 1977, Bull.A.A.S., 9, 701-708.) This catalog contains detailed information on the hardware configurations of 46 microdensitometer systems. It also contains a list of image processing software identified according to function, computer, and source/programmer. A supplement to this Catalog will be published in the Circulars in early 1979.

HIGH ANGULAR RESOLUTION STELLAR INTERFEROMETRY

(Report by the Chairman of the Informal Working Group, Dr J. Davis)

During the XVIth General Assembly of the IAU, at Grenoble in August 1976, an informal meeting was held to discuss high angular resolution optical interferometry. Brief reports from seven groups in Australia, France, the U.K. and the U.S.A. were presented and, in the brief discussion that time permitted, it was clear that there was a great number of common interests and problems that would warrant an extended meeting. A proposal by the Sydney University group for an international meeting on the subject was strongly supported and the outcome was IAU Colloquium No.50 on "High Angular Resolution Stellar Interferometry", which was held at the University of Maryland from 30th August - 1st September, 1978.

The Colloquium was attended by 60 participants from 6 countries. 34 contributions (including 20 invited) were presented in 9 scientific sessions, and visits were made to the U.S. Naval Observatory, Washington, and to the University of

Maryland Amplitude Interferometer at the Goddard Optical Research Facility.

The scientific sessions included contributions on the astronomical potential of high angular resolution stellar interferometry, potential limitations due to atmospheric effects and ground movements, two-aperture interferometry in the visible and infrared including amplitude (small and large aperture), intensity and heterodyne techniques, astrometric applications, speckle interferometry and image restoration. Topics of lively discussion included the effects of the atmosphere, particularly at long baselines, and ways of countering them by developing fringe tracking techniques; the relative merits of pupil and image plane measurements of visibility; and problems related to the selection of sites for interferometry.

The participants were unanimously in support of the following resolution:

"In view of the current growth in interest and activity in high angular resolution interferometry in the visible and infrared regions of the spectrum, this meeting recommends the establishment of a working group on "High Angular Resolution Stellar Interferometry" under the auspices of I.A.U. Commission 9 (Astronomical Instruments).

The scientific proceedings are being published at the University of Sydney, Australia, with J. Davis and W.J. Tango as Editors.

GENERAL DEVELOPMENTS

The Indian Institute of Astrophysics has completed a coudé spectrograph for the 1.02 m reflector at Kavalur; it has been in operation for over a year. Two Schmidt cameras of focal length 24 inches and 112 inches are used with a grating of 400 grooves/mm blazed at 4000Å in the third order. An image tube is also used with the long focus camera. A new echelle spectrograph has just been placed in operation at the coudé focus with cameras of focal lengths 7 inches and 20 inches which give dispersions of 10Å/mm and 3.5Å/mm respectively in the red region.

Bappu (Kodaikanal Observatory Bulletin Series A.2,64,1977) describes a rapid-scan single-channel spectrum scanner with data acquisition by a mini-computer. The instrument is in use at the cassegrain focus for continuum flux measures, photometric spectral indices and low resolution line profile studies.

Bhattacharyya and Sundareswaran have in use (Kodaikanal Observatory Bulletin Series, A., 2, 69, 1977) a fast photometer for the regular recording of lunar occultations. The equipment provides time resolution better than one millisecond.

The Royal Observatory, Belgium, have also constructed some new equipment for the timing of occultations. The equipment consists of a TV camera with an image amplifier mounted on a 45 cm aperture Zeiss refractor. A monitor screen, as well as a magnetoscope and a time-signal-generator, is used to record sequences of images at each observed occultation. An examination of the sequences image by image leads to the determination of the occultation times with an accuracy of some ±0.02 seconds. The results are, of course, not affected by personal equations. Stars of magnitude 10 have been recorded by dark limb (but the limb was seen on the monitor screen). The equipment has been operational since the end of 1977.

At the Main Astronomical Observatory of the U.S.S.R. Academy of Sciences (Pulkovo) a mobile solar telescope was made supplied with a spectrograph and monitor (D = 500 mm; 1:48, spectrograph dispersion 0.5-1Å/mm, spectral range 3800-7000Å). The telescope has been installed at Pamir (altitude 4300 m). A method of taking photographs at moments of best seeing was elaborated (Karpinsky, V.N., Kononovich, E.V., Kupriakov, Yu.A., Solnechnye Dann., 1977, No.4, p.58). For a study of spatial spectrum of solar granulation a coherence analyser was constructed (Karpinsky, V.N., Mekhanikov, V.V., Solar Physics, 1977, 54, No.1, p.25-30).

At the Crimean Astrophysical Observatory photometry of faint stars is carried out with an I-isocon. Quantum efficiency (DQE) of the television system is equal to 0.04 in the yellow range of the spectrum with exposure time about 0.5 min. Mean square error of a single measurement of the magnitude difference is ±0.08 (Abramenko, A.N. et a., Astron.Circ. No.968, 25 July 1977, p.1-2).

At the State Sternberg Institute a considerable amount of work has been done in the field of designing and building instruments for studies of the quality of astronomical images. An electrophotometer for the image tremor measurement, an interferometer for determining the response function of the Earth's atmosphere, and other instruments have been made.

At the Ural University Observatory (Kourovka) a light emitter with zinc sulphide and $^{90}$Sr luminosity body has been developed. The emitter can be utilized for photoelectric measurements (Pylskaia O.P., P.T.E., 1977, No.5, p.207).

The Astronomical Institute of Utrecht has constructed a superheterodyne receiver for high resolution molecular spectroscopy in the wavelength region from 1.5 mm to 400 μm. This project was started in 1975 in cooperation with the astronomy division of ESTEC (Noordwijk, the Netherlands) by Drs. B. Fitton, Th. de Graauw, H. Nieuwenhuijzen, H. van de Stadt and F. van Vliet.

Two types of detectors have been developed and were used for observations: a Schottky-barrier, broad-band uncooled detector, as well as an InSb, narrow-band He-cooled detector. Frequency-locked carcinotron-type local oscillators were used which are tunable at various frequencies ranging from 220 up to more than 460 GHz. A multi-channel filterbank with integrator multiplexer was built which can be used together with a mini-computer using a specially adopted version of a new computer language, Forth.

Observations were recently obtained with good results at frequencies of 230 GHz and around 266 GHz.

Research is further carried out to construct a small far-infrared optically-pumped laser as an alternative local oscillator, especially for the highest sub-mm frequencies, above 400 GHz.

Theodore Dunham Jr. has designed a versatile coudé spectrograph employing spherical mirror cameras of various focal lengths, with echellete and echelle gratings and with photoelectric and photographic recordings. He has also studied a horizontal-axis Alt-Alt telescope system which will feed a coudé focus with only three reflections (Bull.Amer.Phys. Soc. 123, 116, 1978).

J. RING
President of the Commission.