COMMISSION 9: INSTRUMENTS AND TECHNIQUES (INSTRUMENTS ET TECHNIQUES)

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I. INTRODUCTION

The technology leading to very large aperture telescopes and their optics has progressed well in the period since 1984 and plans for many new large aperture telescopes have been made. Focal plane instrumentation continues to become more sophisticated or more efficient: multi-object capabilities, automatic instrument control and operation, and increasing use of CCDs are examples of areas to which this applies. The proportion of time devoted to observations using two-dimensional photoelectronic detectors has grown substantially at many observatories, particularly with telescopes of moderate aperture; and the use of high quantum efficiency array detectors is now being extended into the infrared spectral region. Important advances have also been made in instrumentation and techniques for ground-based high angular resolution interferometry.

Meetings and workshops on telescopes and their instrumentation that have been held since 1984 include:

- An IAU symposium on Instrumentation and Research Programmes for Small Telescopes took place in Christchurch, New Zealand, in December 1985 (IAU Symposium No. 118, ed. J.B. Hearnshaw and P.L. Cottrell).

- Meetings organised by the International Society for Optical Engineering (SPIE) were held in Tucson, Arizona, in March 1986 (Proc. SPIE, Vol.627, Instrumentation in Astronomy VI, 1986; Proc. SPIE, Vol.628, Advanced Technology Optical Telescopes III, 1986).

- In January 1987, a joint ESO/NOAO workshop on High-Resolution Imaging from the Ground using Interferometric Techniques took place at Oracle, Arizona (Proceedings, ed. J. Goad, NOAO, Tucson, 1987).

- In July 1987, a workshop on Instrumentation for Ground-Based Optical Astronomy was held at the University of California, Santa Cruz.

Other meetings that have taken place in the period under review are cited in the text below.

Commission 9 records its tribute here to Dr. D.S. Brown of Durham University, England, whose untimely death occurred on 17 July 1987. Although not a member of IAU, David Brown was known to many astronomers throughout the world and was one of the most respected and influential figures in the design and manufacture of astronomical optics. As Optical Manager of Sir Howard Grubb Parsons Co. Ltd. of Newcastle-upon-Tyne, and later as Technical Director, David Brown supervised the optical manufacture of many 2-metre class telescopes in the 1950s and 1960s (including those at Sutherland, South Africa; David Dunlap Observatory, Canada; Mount Stromlo, Australia; Helwan, Egypt; and Okayama, Japan). In subsequent years a further succession of high quality large optics was designed, manufactured and tested under his guidance and control, including the 1.0m and 1.2m achromatic correctors for the ESO and Palomar Schmidt telescopes, respectively, and all of the recent large British optical telescopes (the 2.5m Isaac Newton Telescope, the 3.9m Anglo-Australian Telescope, the 1.2m U.K. Schmidt Telescope, the 3.8m U.K. Infrared Telescope, and the 4.2m William Herschel Telescope).

II. NEW TELESCOPES - RECENTLY COMPLETED OR BEING DEVELOPED

With the building and dome of the Keck 10m telescope nearing completion on Mauna Kea, commercial production of the 36 segments of the primary mirror has started. Once the stress-polishing technology has become commercially routine, the aim is to produce one finished segment every three weeks; when these are assembled and aligned to form the complete mirror at the end of 1989, the specification for the combined image is 0.32 arcsec (80% encircled energy diameter; 500nm wavelength) at the f/1.75 prime focus, and 0.4 arcsec at the Nasmyth/Cassegrain foci, excluding seeing contributions. TIW of Sunnyvale, California, is the main contractor for the telescope structure; the dome was manufactured by Coast Steel Ltd (Vancouver); the mirror support structure is managed by the University of California, Berkeley; and the mirror segments are being produced from Schott Zerodur by Itek Corporation. First light with the new telescope is scheduled for 1990.

Development of the Japanese 7.5m telescope will have the highest priority for the new National Astronomical Observatory when it is formed in 1988 (incorporating the present Tokyo Astronomical Observatory). The performance of a 7.5m diameter, 0.2m thick, meniscus primary has been studied using finite element analysis, and wind tunnel tests of the dome have been performed at the University of Kyoto to investigate the effect of wind gusts on the primary mirror support system. Engineering tests on the servo system of the mirror support, using a Shack-Hartmann monitor, are being performed with a 0.6m mirror of thickness 2cm. The site proposed for the telescope is Mauna Kea.

A workshop on the 4 x 8m VLT array of the European Southern Observatory was held in Venice in September 1986 and the Proceedings of that meeting (ed. S. D'Odorico and J.-P. Swings) are obtainable from ESO and give the status of the VLT project at that time. Site testing measurements in Chile are currently being obtained at Cerro Paranal (in the Atacama desert region to the north of La Silla) and these are being compared with measurements from La Silla. Meanwhile, the thin 3.58m Zerodur primary mirror for the ESO New Technology Telescope is being optically figured at Zeiss Oberkochen, and pre-assembly of the mechanical structure of the NTT has been completed at INNSE in Brescia, Italy, prior to shipment to La Silla in 1988.

The 4.2m William Herschel Telescope at La Palma saw first light in mid-1987 and has started its operational phase. Final engineering tests confirmed the high optical quality of the Cervit primary mirror, which is capable of producing 0.3 arcsec images (85% encircled energy diameter). A three-element correcting lens at prime focus gives a 40 arcmin unvignetted field at an effective focal ratio of f/2.8; Cassegrain and Nasmyth foci are also provided.

Also sited at La Palma, the 2.56m Nordic Optical Telescope has been completed mechanically and electrically, and the optics (Schott Zerodur; optical work by Tuorla Optics Laboratory, Turku, Finland) are due to be installed in 1988. The telescope is the result of co-operation between astronomical institutes in Denmark, Finland, Norway and Sweden, together with Iceland.

In India, the new 2.34m telescope became operational in November 1985 and was inaugurated as the Vainu Bappu Telescope in January 1986. A 1.22m infrared telescope has been manufactured and is awaiting installation at a site near Mt. Abu (24 degrees 40 min N; 72 degrees 45 min E), and should be operational in 1988. A project for the construction of a 10m millimetre-wave dish and receiving equipment is making good progress, and the design of a new aperture-synthesis radio telescope has started. This will consist of 30m steerable dishes spaced over baselines extending to 27km in the region near Pune (19 degrees 05 min N; 74 degrees 03 min E) and the anticipated completion date is in the mid-1990s.

Three new telescopes have been built in China in the period under review, each with Ritchey-Chretien optics. A 1.26m infrared telescope with f/2.2 primary was made for Beijing Observatory by Nanjing Astronomical Instrument Factory (NAIF) and has been in operation since 1986; a 1.56m astrometric telescope has been produced in Shanghai for Shanghai Observatory and started operation in 1987; and a 2.16m stellar telescope is being tested at NAIF for Beijing Observatory. Future plans include a 1.5m Schmidt f/2.5 telescope being designed at NAIF and funded by Academia Sinica; and a 60cm solar telescope, with five telescope tubes, is being constructed at NAIF for Beijing Observatory.

In the development programme leading to the manufacture of 8m borosilicate honeycomb mirrors, several blanks up to 1.8m diameter were produced by Angel's group with a 2-metre furnace at Tucson. One of these, which was spun-cast to a focal ratio f/1, will be stressed-lap polished as a demonstration of techniques to be applied to subsequent larger mirrors, and will be used in an advanced technology telescope to be developed by the Vatican and Steward observatories.

The new mirror spin-casting laboratory at Tucson is now complete and has a 12-metre turntable currently holding a 6-metre furnace. This will be used initially to produce two 3.5m mirrors, one of which will have a focal ratio f/1.75 for the Apache Pt. telescope, New Mexico, built by ARC (a consortium of four universities in the U.S.A.); the other will be used by a consortium comprising the Universities of Arizona, Indiana and Wisconsin.

Present plans include the production of five still larger mirrors. A 6.5m will be used with the Multiple Mirror Telescope. Two 8m mirrors will supplied for the Columbus project (a 2 x 8m multiple mirror telescope proposed for Mt. Graham, being developed by the Universities of Arizona, Chicago and Ohio State in partnership with Arcetri Astrophysical Observatory, Italy). Another 8m mirror will be used for the Magellan project (University of Arizona in conjunction with the Carnegie Institute and John Hopkins University), a single-mirror telescope to be sited at Las Campanas, Chile. And a further 8m mirror will be used by the Arizona groups in partnership with the Smithsonian Astrophysical Observatory for a re-defined National New Technology Telescope, with the northern hemisphere one probably to be sited at Mauna Kea.

Development of a telescope using a liquid mirror has been been the goal at Universite Laval (Borra E.F. et al. 1985, Publ.Astr.Soc.Pac. 97, p.454). The intention is to construct a zenith-pointing transit telescope with the primary mirror formed from a rotating container of mercury. The turntable for such a rotating mirror can be provided by a circulating water flotation system operated by a pump; moving, deformable, auxiliary optics would permit the tracking of a star over a wide field. So far, a 1.65m mirror has been made in this way and apertures of 15m or larger are considered to be feasible eventually.

Dominion Astrophysical Observatory, in conjunction with the University of Montreal, have made a proposal for a 2.5m, high angular resolution telescope, the tube of which would be filled with helium to optimise heat transfer and minimise internal seeing effects (as in the solar telescope LEST). Another design being pursued at DAO is the Floating Boule Telescope, a low-cost structure considered capable of supporting mirrors up to 10m diameter. Also at DAO, the Canadian Space Astronomy Data Centre (CSADC) is being established there primarily for reduction and archiving of data from the Space Telescope, but also for handling data from the Canada-France-Hawaii Telescope.

Two large submillimetre telescopes have been constructed in the past two years: the Swedish/ESO 15m telescope (SEST) at La Silla, and the joint British and Dutch 15m James Clerk Maxwell telescope (JCMT) at Mauna Kea. The SEST reflector has a surface profile accuracy of about 50 microns r.m.s. (each of the 176 individual panels has an accuracy of 16 microns r.m.s) and will operate coherently at wavelengths down to 0.8mm (375GHz). It is identical to three other movable telescopes being built in France by the Institut de Radioastronomie Millimetrique, Grenoble, and is designed to operate without a radome or other enclosure in winds up to 50 km per hour.

The JCMT reflector has an overall surface accuracy of about 30 microns and should allow efficient operation down to 0.5mm wavelength. To protect the telescope and allow the surface accuracy to be maintained, it is contained in a rotating enclosure; the viewing aperture is covered with a membrane of woven polytetrafluoroethylene and will allow operation in winds up to 70 km per hour.

III. WIDE-FIELD TELESCOPES

The main facility at Kiso Observatory in Japan is the 1.05m Schmidt telescope there. The control system has been renewed, and a PDS 2020 microdensitometer and upgraded computing and graphic display facilities were installed in 1985. In 1984 (September 14) an earthquake of magnitude 6.8 caused damage at the observatory; the epicentre of the quake was only 8km north of the observatory and 2km below ground, causing damage to the concrete pier of the Schmidt and to the dome shutter. Fortunately the telescope optics were found to be unharmed and no significant change was found in the pointing direction of the telescope polar axis. Nevertheless, it required some six months for the repairs to be completed.

A 45cm Schmidt telescope has been fabricated at the workshops of the Indian Institute of Astrophysics at Kavalur, and became operational in March 1986.

The commissioning by Caltech of the new achromatic corrector plate for the Palomar 1.2m Schmidt telescope prepares the way for a new-epoch multicolour survey of the northern hemisphere skies.

The Nanjing Astronomical Instrument Factory is currently designing a 1.5m f/2.5 Schmidt telescope with achromatic corrector plate. When this is built it will become the largest Schmidt telescope in the world (the current largest being the 1.34m Tautenburg Schmidt).

Interest from other countries has also been shown in building wide-field telescopes of aperture larger than those that exist at present. At a workshop held in Tucson, February 1987, on Instrumentation for Cosmology, the recommendation of the workshop was that a wide-field 4m class telescope should be constructed to carry out a redshift survey of galaxies down to B=19 magnitude over a steradian of sky near the north galactic pole. A field of at least 2 degrees would be required for this and approx. 400 fibres would be used to feed multiple spectrographs.

At another workshop on wide-field telescopes held in April 1986 in Cambridge, England, the three-mirror telescope proposed by Willstrop (1984, Mon. Not. R. astr. Soc. 210, 597; and 1985, 216, 411) was discussed, and some practical work with a scaled prototype is in progress. A mounting system for very large telescopes, with particular application to the classical Schmidt, has been described by Reddish and Simmonds (1987, Mon. Not. R. astr. Soc. 228, 537); pointing in elevation is provided by a flat mirror inclined at 45 degrees to the horizontal; the design has the appearance of a siderostat and the behaviour of an altazimuth telescope.

IV. SOLAR TELESCOPES
(W.C. Livingston)

The goal of high spatial resolution dominates new solar facilities. At La Palma, the Swedish 50cm telescope installed in 1985 has established new performance standards; interferometric tests and speckle observations of stars show that total wavefront errors are 1/15 wave peak-to-peak. White-light granulation sequences confirm this image quality. At Tenerife, the German 70cm vacuum tower is going into operation with the aim of feeding a large and efficient echelle spectrograph. Engineers at LEST (Large European Solar Telescope) have demonstrated that a helium filled telescope is seeing-free and that thin entrance windows are practical.

Other efforts are towards low polarization telescopes. THEMIS (Telescope Heliographique pour l'Etude du Magnetisme at des Instabilites Solares) is now under construction, and LEST is in the planning and site selection phase with a difficult choice between La Palma and Mauna Kea. For solar oscillation studies, the prototype Global Oscillations Network Group (GONG) instrument is under test and a series of experiments are being conducted at the South Pole where, with luck, continuous runs of several days will be realised.

V. TECHNIQUES

Limitations of space permit mention here only of a few, highly selected, developments in techniques and focal plane instrumentation.

Many observatories now have fibre optic systems that are in routine use on telescopes for multiple-object spectroscopy or photometry. Examples of existing systems are: the MX fibre-coupled spectrometer (with automated and remote controlled fibre positioning) developed at Steward Observatory, Arizona; the Anglo-Australian Telescope fibre system with AUTOFIB (also automated and remote controlled); OPTOPUS at the ESO 3.6m telescope; and FLAIR, a wide-field (40 square degree) multi-object system in use at the U.K. Schmidt Telescope.

There are many other applications of fibres that are now in routine use at some observatories, such as image scrambling, image slicing, extended-object image sampling, and image transfer from the telescope to a coude station or to floor-mounted instruments.

A new development by the Advanced Concept Exploration group of NOAO is a two-beam interferometer using single-mode fibres with which white-light fringes have been obtained. Thus, long baseline interferometry may become possible using single-mode fibres as waveguides.

Adaptive optics compensation of atmospheric seeing effects has resurfaced as a real possibility for observational optical astronomy; this follows a period when practical limitations (guide star brightness requirements and isoplanatic field restrictions) were seemingly intractable.

Good progress has been made with wavefront-tilt compensation, particularly at the University of Hawaii, and several other institutes (e.g. NOAO and ESO) are devoting effort to this. At the DAO, a high angular resolution CCD camera is being developed for the CFHT prime focus with an optical package that includes a piezo-electric wavefront-tilt compensator and a fast shutter system for discriminating automatically between moments of good and poor atmospheric seeing, and using only the best.

In 1985, Foy and Labeyrie (Astron. Astrophys. 152, L29) suggested that backscattered laser light from atmospheric layers at altitudes up to 100km would give enough photons to activate a fast adaptive optical system, and that in this way an artificial guide star could be created. The first experiments using this method have now been reported by L.A. Thompson and C.S. Gardner (1987, Nature 328, p. 229) using University of Hawaii 2.2m and 0.6m telescopes at Mauna Kea and lidar equipment developed by the University of Illinois.

Another method of obtaining diffraction-limited images with large ground-based telescopes is to apply aperture synthesis and phase closure techniques to short exposure images taken with an array of apertures placed over the primary mirror, each sub-aperture being no larger than the scale size r(0) of the atmospheric fluctuations. The first reconstructed images obtained by this method at optical wavelengths using the 2.5m Isaac Newton Telescope at La Palma have been reported by Haniff et al.(1987, Nature 328, p. 694).

Two dimensional infrared detector arrays are now available and have applications similar to those of CCDs at visible wavelengths, i.e. high quantum efficiency direct imaging and spectroscopy. IRCAM is an IR imager developed at the Royal Observatory, Edinburgh, and now in operation at UKIRT, Hawaii. It employs a thinned, back-illuminated, silicon-hybridised 62 x 58 array of photovoltaic indium antimonide diodes and gives quantum efficiencies greater than 60 per cent at wavelengths from 1 to 5 microns. Similar technology is being used by NOAO to produce IR imagers for the telescopes at Kitt Peak and CTIO, Cerro Tololo. The ESO system (IRSPEC) that has been in use since 1985 is a cooled grating spectrometer equipped with an array of 32 indium antimonide diodes; ESO are currently experimenting with 64 x 64 mercury-cadmium-telluride arrays for the 1 to 4.2 micron region with IRSPEC. 128 x 128 arrays are also becoming available now. An account of developments and applications of IR arrays is given in the Proceedings of a workshop on Ground-Based Astronomical Observations with IR Array Detectors held in Hilo, Hawaii, in 1987 (Infrared Astronomy with Arrays, ed. C.G. Wynn-Williams and E.E. Becklin, published by University of Hawaii, Hilo, 1987).

Supernova 1987A triggered the occasional ad hoc construction of some special instruments as well as harnessing large amounts of observing time with existing ones. At the Anglo-Australian Telescope at Siding Spring Observatory, advantage was taken of the supernova's brightness to build an ultra-high resolution spectrograph. This used a Littrow-mounted prism-dispersed 204 x 408mm echelle grating (79 g/mm) to reach an attained resolving power of 570,000, or 10 milliangstroms at sodium D.

VI. CCD DETECTORS
(Report by G.A.H. Walker, Chairman of the Working Group on Photoelectronic Detectors)

Very valuable and complete compilations on the state of CCD technology and their critical application to astronomy are contained in the Proceedings of a conference held at Observatoire d'Haute Provence in June 1986, published by and available from ESO; and in three special issues of Optical Engineering Vol.26, Nos.8,9,10 (available from SPIE, PO Box 10, Bellingham, Washington 98227-0010, U.S.A.). These are highly recommended to anyone involved in the use of CCDs.

Progress in the development of new, low-noise, large-format CCDs suitable for astronomy has not lived up to the promise held out at the 1985 IAU General Assembly meeting in Delhi. Any group outside the U.S.A. that plans to build a CCD detection system for either in-focus photometry or for spectroscopy has little choice. The withdrawal of RCA from CCD production was known at the time of the Delhi meeting. The few available double density RCA 640x1024 devices are being used in both thinned and unthinned versions. The former tends to crinkle which makes it unsuitable for fast optics.

Tektronix has been unable to deliver grade one 512x512 or 2048x2048 devices in either front or rear illuminated versions. Those products up to mid-1987 contained an unacceptably large number of potential pockets that inhibit the complete transfer of charge during readout. Such pockets are also found in even the best CCDs from other manufacturers. At the time of writing, Tektronix has moved production to a new facility where they hope that, with improved quality control, grade one 512M devices may become available in late 1987.

Thomson CSF and English Electric Valve Co. (ex-GEC) remain reliable sources for the TH31133 (384x576, 23 micron pixel) and P8603A (385x576, 22micron pixel) CCDs, respectively. Both devices are operated with a readout noise of between 10 and 20 electrons rms. They are unthinned with consequently lower peak quantum efficiency (30 per cent) than thinned devices. Both companies are experimenting with large format devices. EEV is developing a single, large device while Thomson is considering a closely butted mosaic of special versions of their 384x576 device.

A fluorescent coating developed at ESO (Cullum, M. et al. 1985, Astron. Astrophys. 153, L1) has been used successfully to extend the sensitivity of these devices into the uv at a level of about 20 per cent. A uv flooding technique has also been used at Steward Observatory (see: Leach, R.W. and Lesser, M.P. 1987, Publ.Astr.Soc.Pac. 99, p.668), from original work at JPL, to improve blue and uv responses.

Kodak is producing a 1035x1320 CCD with 7 micron pixels that has interesting possibilities for astronomy. The quantum efficiency curve has several strong peaks and valleys but is otherwise typical for a thick device. Some reports suggest that the readout noise could be less than 30 electrons rms. E.G.& G. Reticon is also developing CCDs suitable for astronomy with a view to marketing them eventually.

Linear arrays of silicon diodes (Reticons) are still used routinely for spectroscopy at many observatories and a continued supply of these devices seems assured. Several new systems have been commissioned since the Delhi meeting. Tull at the University of Texas has commissioned the Octicon in the coude spectrograph of the 2.5m telescope. It consists of eight 1872F/30 E.G.& G. Reticons in line. Several groups are building detection systems based on the 4096 Reticon array. Thomson CSF has developed a 2x2048 diode array in which the linear arrays are separated by 500 micron and the diode dimensions are 13x750 microns. It uses CCD output multiplexers and noise levels of 350 electrons rms are reported. Several new intensified Reticons have been commissioned for photon counting spectroscopy in the spectrograph mode since the Delhi meeting.

While Reticons can, with care, be routinely calibrated photometrically to better than 0.1 per cent, it has not been clearly demonstrated that CCDs can be calibrated to better than 1 per cent. This matter will be an important one for discussion at the Baltimore General Assembly meeting in 1988.

VII. ASTRONOMICAL PHOTOGRAPHY
(Report by the Chairman of the Working Group, D.F. Malin)

The principal activity since the General Assembly in New Delhi was a workshop meeting of the Working Group on Astronomical Photography held in Jena in the German Democratic Republic between April 21 and 24, 1987. The scientific sessions were conducted in the Hall of the University of Jena and were attended by over 60 delegates from 13 countries. More than half of the attendees were from Eastern Europe with 26 from the host country and 14 from West Germany.

During the scientific sessions 36 papers were presented on the usual wide range of topics covered at such meetings. While many of these concerned the practicalities of hypersensitising and processing photographic materials, considerable attention was given to calibration problems and to the machine measurement of plates. These topics were also reflected in a series of poster papers that were available for inspection in the entrance to the Hall.

The town of Jena was a very appropriate setting for our meeting. Apart from the formal scientific presentations, delegates had the opportunity to make an evening visit to the Karl Schwarzschild Observatory, and one full day was devoted to a visit to the nearby historic town of Weimar and to the optical factory of Carl Zeiss Jena where we saw the assembly of a very wide range of equipment with astronomical applications, from planetarium projectors to 2m telescopes.

Apart from the scientific activities we also held a short meeting of the Working Group Organising Committee on April 23. Present were:

David Malin (Australia) - Chairman; Siegfried Marx (GDR) - Secretary;
Olga Dokuchaeva (USSR); Keiichi Ishida (Japan); Jean-Louis Heudier (France);
Milcho Tsvetkov (Bulgaria); Richard West (FRG); Olga Zichova (Czechoslovakia).

1. Report of the Organising Committee Meeting:
A) We have received information from Schott Glaswerke in Mainz that, contrary to rumour, they did intend to continue the manufacture of filter glasses in the large sizes suitable for large telescopes. However, it was clear that not all coloured glass filters would be available at all times due to a rationalisation of their manufacturing programme. A letter to Carl Zeiss Jena enquiring about their range of filters produced no response. A similar letter to the Hoya Corporation in Tokyo revealed that this company do make some glass filters of interest to astronomers but their maximum size is 165 x 165mm.

B) Though at least one observatory (U.K. Schmidt) has experimented with large sheet film in place of glass plates, there are as yet no spectroscopic emulsions coated on sheet films. The U.K. Schmidt experiments were focus tests using duplicating film cut down to 355mm squares. There is no evidence that new or existing spectroscopic emulsions (from Kodak) will be coated on anything other than glass, though it has been noted that Kodak's Technical Pan film Type 2415 (not strictly a spectroscopic emulsion) is now available to special order in 14 x 14 inch size sheets of film.

C) A survey to identify those batches of Kodak plates that respond well to hydrogen hypersensitising has not been very successful. Only one reply was received from the 15 circulars sent to people and organisations that were thought to treat hypering seriously. At least two more correspondents have promised results however, so these are awaited with interest.

2. The Future of the Working Group:
This topic was discussed at some length especially in the light of the AAS photographic group's decision to broaden their remit to include all types of

two-dimensional detectors. No firm decision was made on this but my feeling is that the Photographic Working Group should remain as it is, particularly since groups considering other 2-D detectors are well catered for in Commission 9.

3. Plate Costs:

This subject is raised with increasing vigour at every meeting. It is clear that overall, the cost of plates is now a serious problem and it has reached the point where it is inhibiting research. There was also evidence presented that plate costs varied greatly from country to country. The most extreme example of this came from Prof. Ishida who said that one plate for the Kiso Schmidt now cost 30,000 yen, or about 200 US dollars.

It became evident at the meeting that the East German manufacturer Orwo had at least one emulsion on glass that may be of interest to astronomers. This material is identified as ZU21 and is a blue-sensitive emulsion with properties somewhere between 103aO and IIaO. However its most attractive feature is its cost, which is apparently much less than the Kodak equivalent.

4. New Photographic Emulsions:

In the early part of this year the photographic grapevine buzzed with rumours of a new astronomical emulsion from Eastman Kodak based on the T-grain technology which has been so successful, firstly in colour film, more recently on glass. As yet I am not aware of any name or code number for the new material. The following report is derived in part from my own experience with the samples supplied and from private communications from colleagues at the U.K. and Palomar Schmidt telescopes.

The material released for test appears to be quite similar to the emulsion that is marketed as T-max 100. It has a spectral response that terminates in the red at about 630nm, has poor blue sensitivity (compared with IIIaF) and has a number of prominent sharp peaks in the green and yellow parts of its sensitivity curve. In this regard it is quite unlike any of the normal astronomical emulsions.

When processed for 5 minutes in D19 the characteristic curve is long, straight and shallow, i.e. the emulsion has low contrast (gamma = 1.2 to 1.5), wide dynamic range and small toe region. It is likely therefore that its peak quantum efficiency for astronomical use will occur at a low density and the DQE curve will be broad, unlike the IIIa series. Of course, the low contrast (which might be increased by different developers or post-process copying) is of no advantage for the detection of faint objects. Again the gross properties are those of a general purpose camera film.

The T-grain emulsion on glass is extremely slow for long exposures. With a 15 minute exposure to 3200 degree K tungsten light through a GG 385 filter, the unhypered material is a factor of 3 or 4 times slower than an unhypered IIIaF plate (batch 1L5) and a factor of 2 slower than an unhypered IIIaJ (batch 1C5). However, the T-grain emulsion is about 5 times faster than 2415 on glass (153-01, manufactured 03/85) exposed as above. Like 2415, T-grain on glass also responds very slowly to hydrogen hypering, but worthwhile speed increases are obtained with drastic treatment (e.g. a 2 hour bake in pure hydrogen, at 65 degrees C). The best white-light speed we obtained was about that of an unhypered IIaO at a desity of 0.6 above a fog of 0.2 (up from an as-received fog of 0.08), a 5-fold speed increase. Interestingly, the same extreme hypering recipe produced a similar speed for 2415 on glass, a gain of about 12 times. Subjectively, the grain structure of the new emulsion is similar to that of the IIIa products but some measurements indicate much better signal-to-noise than IIIa materials, though more careful measurements will be needed to confirm this.

Overall, however, the low speed, low contrast, and peculiar spectral sensitisation of T-grain on glass will not commend it to professional astronomers though much more needs to be done to explore the material fully, especially if the spectral sensitivity is either improved in the blue or extended in the red.

5. The Next Meeting:

It is planned to hold the next Working Group meeting in Baltimore as part of the activities of Commission 9 during the 1988 IAU General Assembly. Preliminary plans are that we hold two half-day sessions, one of these for the presentation of mainly photographic results to, and by, those of us who are interested in photographic astronomy; and the other with the much wider purpose of presenting astronomical results derived by photographic means. It was agreed that it will be important to show that photography is still an important source of astronomical data and discovery, and is entirely competitive with other techniques and in some cases superior. To this end, we will encourage our colleagues to bring to Baltimore large numbers of posters illustrating new and exciting applications of photography to capture the interest of what will undoubtedly be a very large and important meeting.

VIII. HIGH ANGULAR RESOLUTION INTERFEROMETRY

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

a) Introduction:

Interest in high angular resolution interferometry has increased dramatically in the period 1984-7. Significant advances in instrumentation have occurred and several important observational demonstrations of instruments and techniques have been made. These include angular diameter measurements to the order of 1% accuracy by amplitude interferometry in the infrared [1] and the visual [2], fringe detection between two large aperture telescopes [3], fringe tracking and large angle astrometry with accuracy of the order of 70 mas in a highly automated prototype astrometric interferometer [4], the development of double Fourier spatio-spectral interferometry [5], and the measurement of closure phase at optical wavelengths [6].

The field is expanding rapidly and to assist members of the Working Group and those entering the field, lists of publications in high angular resolution interferometry have been prepared, based on responses from members of the Group, covering the years 1983-5 and 1986. Although the lists are not exhaustive, due to an incomplete response from members of the Working Group, the lists have proved useful and are available from the Chairman of the Group. It is intended that these lists be produced early in each year to cover publications in the previous year.

b) Single-Aperture Interferometry:

Speckle interferometry is now regarded as a well established technique enabling the full diffraction limited resolution of a telescope to be realised in measurements of angular dimensions of single and multiple objects. The field was reviewed by Dainty in 1984 [7] who noted that the technique was by then over a decade old and that some 80 papers primarily concerned with astronomical results had been published. Examples of applications include the study of binary stars where the technique has been particularly productive, the determination of diameters for satellites of Pluto, Uranus and Neptune, Pluto itself and of asteroids, and studies of solar granulation. Extragalactic applications include the resolution of components of a quasar system, the determination of the diameters of planetary nebulae in the SMC and LMC, and more recently the study of SN1987a in the LMC.

The reconstruction of images from interferometric data has been the subject of considerable activity, both theoretical and practical, and has been included in the programs of several meetings [8,9,10]. The difficulties encountered in efforts to reconstruct images from the modulus of the fringe visibility alone have led to an appreciation of the need to preserve phase information. As a result, considerable attention has been given to the development of methods that yield object phase information including speckle holography, shift-and-add, Knox-Thompson and the triple correlation technique. Roddier has given a concise review of the various methods [11] and has also prepared for publication a major review on "Interferometric Imaging in Optical Astronomy", which includes a near exhaustive reference list. Images of astronomical objects yielding important astrophysical results are now being obtained and these include images of α Ori and its envelope, images revealing multiple stars in objects such as η Car, images of asteroids, and of circumstellar dust shells and emission regions, etc. These high resolution imaging techniques will be extremely important for the new very large optical telescopes such as the Keck Telescope.

The Multiple-Mirror Telescope (MMT) has been operated with all six mirrors optically co-phased to give the complete u-v plane cover of an appropriately masked 6.86m aperture telescope and diffraction limited images have been obtained [12].

Observations using masks with a number of r(0) diameter apertures covering large telescope apertures have succeeded in measuring closure phases at optical wavelengths [6]. Image reconstruction techniques developed for aperture synthesis in radio astronomy have been applied successfully to optical closure phase data [13]. This work has excited considerable interest in the prospect of using closure phases with apertures separated by long baselines. This will be discussed in the next section.

An optical aperture synthesis technique (TOAST) applicable to ground-based telescopes, and which would provide model independent image reconstruction, has been proposed [14].

The use of adaptive optics to provide diffraction limited images for large aperture telescopes is under active investigation [15] and it has been suggested that an artificial reference source might be provided by back-scattering of a lasar beam from high altitude [16].

c) Two-Aperture Interferometry:

Two prototype amplitude interferometers with effective apertures r(0) and incorporating piezo-electrically driven star tracking systems became operational in 1985 and 1986.

The 11.4m N-S baseline prototype stellar interferometer developed by the University of Sydney commenced observations in October 1985. It is being used in a test and development program for a very high angular resolution instrument but as a demonstration of its performance the angular diameter of Sirius has been measured with an accuracy of +/- 1.5% [2]. In parallel with this program, and based on the experience gained from it, construction of a new Sydney University Stellar Interferometer (SUSI) [17] has commenced at Culgoora, northern NSW, Australia. The new instrument will have siderostats with effective apertures of 14cm and N-S baselines covering the range 5-640 metres.

The Mark III astrometric interferometer on Mt. Wilson [4,18] first observed fringes in September 1986 with an initial 12m N-S baseline. The instrument is the result of collaboration between the Smithsonian Astrophysical Observatory, MIT, the U.S. Naval Research Laboratories and the U.S. Naval Observatory. It is highly automated with computer controlled star acquisition and it features a fringe-tracking path equalisation system. Early in its test program 165 measurments of 23 stars were obtained in one night and large angle astrometric measurements in one color repeat to about 70mas from night to night. Preliminary two-color measurements indicate that they can reduce the atmospheric error by approximately a factor of five. Additional metrology systems, the extension of the baseline to 20m N-S and the addition of 9m NE-SW and NW-SE baselines are being implemented.

The original two telescope (0.26m aperture) interferometer at CERGA known as I2T has evolved and been extended since it was started in 1974. The current N-S baseline range of 6-67m is being extended to give baselines up to 144m. The beam-combining optics have been replaced and 0.25nm spectral resolution is now available [19]. The importance of the high spectral resolution has been demonstrated in measurements of the Be star γ Cas in the continuum and in the $H\alpha$ emission line [20] from which the emission envelope can be distinguished from the star. Observations made with the PAPA detector have allowed the effect of sampling time on the measured visibility to be investigated [19]. The instrument has also been used in the infrared to provide angular diameter measurements of extremely high precision (1%) [1].

The larger CERGA interferometer, GI2T, has observed fringes with the full 1.5m apertures of its two telescopes [21] following initial fringe observations with reduced apertures (0.42m) and a baseline of 13.8m [3]. Work is under way to reduce problems, including vibration, encountered in the first observations and to develop an improved fringe detection system.

In the infrared a two telescope 10 micron heterodyne interferometer is under construction at Berkeley [22]. Townes reports that the first 1.65m aperture telescope is performing well in tracking tests and the second telescope is complete. A site on Mt. Wilson has been prepared for the installation of the telescopes as an interferometer. The insrument will be used for both high angular resolution measurements and precision astrometry.

d) Multi-Aperture Interferometry:

The demonstration of closure phase measurements at optical wavelengths [6] has brought the prospect of imaging from multi-aperture interferometry closer to reality. Several groups are now constructing or carrying out feasibility/design studies of multi-aperture instruments with high resolution imaging in mind. Included are:

1. Development of the CERGA I2T into I4T [19]. Plans are in hand to add a 60m range of E-W baselines to form a cross configuration with the N-S baselines of the I2T and to add two telescopes to give a total of four 0.26m telescopes. The completed instrument will be used to measure closure phases and to reconstruct images.

2. The Sydney University Stellar Interferometer (SUSI) [17] now under construction. The first station of an E-W array of siderostats is included in the initial construction of SUSI and the design will permit the future combination of up to 4 beams for the measurement of closure phase and to reconstruct images.

3. The Cambridge Optical Aperture Synthesis Telescope (COAST) project [13]. The design is based on an array of four siderostats with effective apertures of 40cm to give six baselines up to 100m. The instrument will initially operate in the spectral range 800-1600nm and is expected to reach magnitudes of at least 10 and possibly 14.

4. The ESO Very Large Telescope project. The VLT includes four 8m telescopes distributed over a range of about 100m. It is planned to phase the four telescopes for interferometric operation. Two additional smaller, movable telescopes

are proposed to provide improved u-v plane coverage for very high resolution imaging.

5. Design study by the Centre for High Angular Resolution Astronomy (CHARA) at Georgia State University. A detailed design study is being conducted and is considering an array of 1m telescopes to give a maximum baseline in the 300-400m range.

In addition there are several projects starting in 1987. These include a preliminary design study for a United States Naval Observatory astrometric array based on experience with the Mk. III prototype astrometric interferometer [18], a collaborative project between the Smithsonian Astrophysical Observatory and the Universities of Massachusetts and Wyoming to develop an Interferometric Optical Telescope Array (IOTA) for optical and infrared wavelengths on Mount Hopkins in Arizona, and a National Optical Astronomy Observatories project to develop an interferometric array for the infrared/optical. Proposals in the discussion stage include the ambitious Optical Very Large Array (OVLA) [21].

e) General Developments:

There have been a number of developments with implications for high angular resolution interferomtry that are relevant to many or all of the preceding sections. These include experimental work on the use of optical fibers to link telescopes for coherent operation [23] and an analysis of group delay fringe tracking for faint operation of long baseline interferometers [24]. The importance of two dimensional photon-counting cameras for all forms of high angular resolution interferometry has been clearly demonstrated by the application of the PAPA camera to speckle interferometry [25], fringe visibility measurements [19], and its use in a star tracker for a long baseline stellar interferometer [26].

The development and demonstration of double Fourier interferometry [5] to provide spatial information for all spectral elements within the observed bandpass simultaneously is another important development. It is particularly well suited for differential measurements.

f) Interferometry From Space:

A number of approaches to achieving high angular resolution in space have been proposed including those with the acronyms COSMIC, OASIS, SAMSI, SPI, and TRIO. These have been developed to varying degrees and have been discussed at a number of colloquia and workshops devoted to interferometric imaging from space [8, 9, 27, 28]. Attention is currently directed towards connected telescope arrays using either the COSMIC [29] or OASIS [30] approaches, and critical technical issues such as structure stiffness etc., are the subject of a NASA study at JPL. No decision has yet been made regarding which approach should be chosen for intensive study but efforts to reach such a decision are being made through regular ESA-NASA workshops, the most recent being the ESA Workshop on "Optical Interferometry in Space" held at Granada in June 1987 and to be published by ESA [31].

A micro-arcsecond astrometric interferometer for space, known as POINTS (Precision Optical INTerferometer in Space), has been proposed [32] and collaboration between the Harvard-Smithsonian Center for Astrophysics and the Perkin-Elmer Corporation has been established for the development, manufacture and laboratory testing of critical optical components.

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IX. Acknowledgements

The unattributed sections in this report have been prepared with the help of information supplied by many contributors, including the following: A. Ardeberg, H. Ando, J.R.P. Angel, J.M. Beckers, J.C. Bhattacharyya, B.P. Fort, P.R.Gillingham, W. Grundmann, Hu Ning-sheng, K. Ishida, T.J. Lee, I.S. McLean, J. Nelson, E.H. Richardson, M.G. Smith, F.G. Watson, R.M. West, Y. Yamashita.

C.M. Humphries
President of Commission