9. INSTRUMENTS AND TECHNIQUES (INSTRUMENTS ET TECHNIQUES)

PRESIDENT: E.H. Richardson
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I. MEETING AT THE 6 METRE TELESCOPE

The major activity organized by Commission 9 was IAU Colloquium 67, Instrumentation for Large Telescopes, held 8-10 Sept., 1981, on a portion of the observing floor of the 6 metre telescope of the Special Astrophysical Observatory, USSR. The cooling coils in the floor were turned off and a rug laid. The enormous BTA (Bolshoi Altazimuth Telescope) provided a spectacular back drop to the 88 participants. Between sessions, the particpants were shown every detail of the telescope by its Chief Designer, Dr. B. K. Ioannisiani, and SAO staff. Night observations continued: speckle interferometry.

The Proceedings, edited by C. M. Humphries, and consisting of some 40 titles and three photographs at the BTA, will be published by Reidel as "Instrumentation for Astronomy with Large Optical Telescopes." There are four sections. 1) Telescopes (existing, e.g. 6 metre, MMT and CFHT; under construction, e.g. 4.2 metre Herschel and Iraqi 3.5 metre; and planned, e.g. 7.6 metre Texas and USSR 6 metre polar); 2) Spectrographs (including multi-object, wide field, and with and without slit); 3) Interferometers; and 4) Detectors. The smallest telescope described, 5 cm, is located at the most extreme site, the South Pole, and is used to measure solar oscillations by the Observatoire de Nice.

Panoramic, 360 degree photographs were taken inside the BTA dome for the H. R. MacMillan Planetarium, Vancouver, Canada. (It gives the Planetarium audience the illusion of being inside the BTA dome with the 6 metre telescope which was turned horizontal with the mirror cover open for the photographs.)

II. TUCSON MEETINGS

On the occasion of the commissioning of the Multiple Mirror Telescope on Mt. Hopkins, a conference on "The MMT and the Future of Ground-Based Astronomy" was held at the University of Arizona, Tucson, 9 May 1979. It is published as the Smithsonian Astrophysical Observatory Special Report 385. The editor is T. C. Weeks.

A larger meeting was held the next year: "Optical and Infrared Telescopes for the 1990s", 7-12 January 1980, a Kitt Peak National Observatory Conference, edited by Adelaide Hewitt. There are 72 titles and 202 participants.

"SPIE - The International Society for Optical Engineering" sponsored a conference in Tucson in January 1979: "Instrumentation in Astronomy III", Volume 172.

Two conferences are planned for Tucson in 1982, both sponsored by SPIE and The American Astronomical Society: "Instrumentation in Astronomy - IV", 8-10 March, and "Advanced Technology Optical Telescopes" 11-13 March.

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III. OTHER MEETINGS

An ESO Conference was held at Garching, 24-27 March 1981, on the "Scientific Importance of High Angular Resolution at Infrared and Optical Wavelengths," edited by M.H. Ulrich and K. Kjar. There were 119 participants and 37 papers.

Commission 9 joined with the International Commission for Optics for the Congress and Twelfth Assembly, "ICO-12", held in Graz, Austria, 31 August to 5 September, 1981. Proceedings will be published in Optica Acta. A progress report on the NASA Space Telescope is included.

Several other meetings of the SPIE were related to astronomical instruments. The titles, volume number, and place are as follows: IR Image Sensor Technology, Volume 225 (Washington, D.C. 1980); Periodic Structures, Gratings, Moire Patterns and Diffraction Phonomena, Volume 240 (San Diego 1980); Cryogenically Cooled Sensor Technology, Volume 245 (San Diego 1980); Applications of Digital Image Processing to Astronomy, Volume 264 (Pasadena 1980); IR Astronomy -- Scientific/Military Thrusts and Instrumentation, Volume 280 (Washington, D.C. 1981); Solid State Imagers for Astronomy, Volume 290 (Harvard 1981); Mosaic Focal Plane Methodologies II, Volume 331 (San Diego 1981).

IV. PROGRESS OF TELESCOPE PROJECTS

At the SAO, a new 6 metre mirror of low (but not zero) expansion material has been substituted for the original (which is now outside in storage and might be used for an inexpensive, stationary polar telescope designed to study very faint objects in a 36 arcmin field near the pole). The telescope can now concentrate up to 90% of the light in 0.82 ± 0.05 arcsec. For improvement of the thermal environment of the mirror, a local fan system has been installed.

A 6 metre mirror blank of "Sitall" zero expansion material was cast but rejected as not good enough for polishing.

The Multiple Mirror Telescope on Mt. Hopkins, Arizona, consists of six 1.8 metre axially symmetric mirrors on a single mount. The MMT and its instruments are described in the publications mentioned above. Latest reports are that the seeing has proven to be outstandingly good on Mt. Hopkins and in the MMT building. The laser stabilization system was not successful but the mechanical stability of the mounting is very good and permits tracking on the superimposed images for several minutes without correction. A new system will be installed using computer controlled off-set guiding from each mirror to automatically keep the images superimposed and will have the added advantage of removing seeing induced image motion from the individual mirrors resulting in better light concentration than could be achieved from a single telescope of equivalent aperture: 4.4 metres.

The CFH (Canada-France-Hawaii) 3.6 metre telescope is now in regular operation but all of the original instrumentation is not yet completed. Standard equipment at the Prime Focus is a modified Wynne corrector with the option of replacing the third element by a special wedged element with a coarse grating deposited thereon, called a "grens". This combination produces slitless spectra over a one degree field with a magnitude limit in a 1.5 hour exposure of 21 at 1000 A/mm and 22 at 2000 A/mm on IIa-J emulsion.

The first visiting observer at the CFHT was G. Lemaitre of Marseille Observatory (March 1980) who brought with him an aspherized grating spectrograph which he had built using his elastic deformation technique. A plane aspherized grating replaces the more common grating + twice-through Schmidt plate combination. This 90 A/mm spectrograph uses a photographic plate as detector, covers a wide region (3000 - 5000A) and reached 18th magnitude in 2 hrs. In 1981,

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a concave holographic reflection grating spectrograph was brought by the University of British Columbia and used at the prime focus. It consisted of only the grating, a flat diagonal mirror, and two windows for the cold box and the microchannel intensified CCD detector. The spectrograph covers the region from 4000 to 8000A at 160 A/mm, 12% of which is intercepted by the CCD. The 22nd magnitude was reached in 30 minutes at 12A resolution in the 3900-4400A region with a signal-to-noise ratio of 5.

The dome design of the CFHT has been exceptionally successful in preserving the seeing which has been one arcsec or less about one half of the time with 0.6 arcsec a common occurrence. The small-mirror, turreted, high reflection coude mirror train has succeeded in reducing both light loss and seeing degradation. The first coude spectrograph, with dispersions as high as 2.7 A/mm, is in regular operation but not yet in its final form. A Reticon is the most popular detector and changes in velocity of 25 metres/sec can be detected using a Hydrogen Flouride absorption cell for the wavelength comparison. A Michelson interferometer, designed for the Cass focus, is in temporary use at the coude focus. The F/8 Cassegrain mirror was finished in 1981 and after it is installed and tested the 1.8 metre test sphere will be used as a camera in the coude spectrograph.

A horizontal solar telescope was constructed at Pulkovo Observatory and mounted in Cuba. The diameter of the coelostat is 300 mm and the primary mirror is 290 mm, 9700 mm focal length. The spectral range is 3900-6600A.

The nearly complete 3.5 metre telescope of the Max Plank Institute will be installed in Spain in 1982. A similar 3.5 metre telescope, has been ordered by the Iraqi National Observatory.

In Argentina a 2.2 metre telescope is being erected at El Leoncito Observatory. This telescope is a twin of the KPNO 84 inch, but the coude system will be changed to one using small, high reflectance mirrors.

The Burrell Schmidt 60 cm F/3.5 telescope was moved from Cleveland to Kitt Peak, and a new 10 degree dense flint objective prism added to complement the existing 4 and 2 degree prisms.

In China, 2.16 and 1.56 metre telescopes are under construction. Zero-expansion glass-ceramic blanks up to 3.5 metre diameter can be produced, called "VO-2."

The 4.2 metre, altaziumth, William Herschel Telescope has been funded and is under construction. It will be installed on La Palma as part of the Observatorio del Roque de los Muchachos, at an altitude of 2300 metres in the Canary islands. Among the proposed instruments is a novel collimatorless spectrograph. The 2.5 metre Isaac Newton Telescope is already being moved to La Palma.

IV. FUTURE TELESCOPES

A 25 metre telescope with a spherical, mosaic primary mirror (and a 6 metre monolithic secondary mirror) has been proposed in the USSR. In this connection, a 1.2 metre telescope having a spherical primary composed of 0.4 metre segments has been tested at the Crimean Astrophysical Observatory (Proceedings of MMT Conference). Two-mirror designs for spherical primaries have been studied (B. A. Gurnasheva et al., Izv Krimskoy Astrofiz Observ 1981, 63.) At Odessa Astronomical Observatory, a three mirror system with a spherical primary was designed and tested.

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Universities of Arizona, California, and Texas has been funded for research to develop the technology for a 15 metre telescope. It is planned to decide between two approaches in 1983: the MMT (multiple mirror telescope) and the SMT (segmented mirror telescope). For the MMT honeycomb Pyrex mirror blanks are being cast at the U of A and will be tested on the existing MMT. For the SMT, 2 metre off-axis paraboloidal segments, 7.5 cm thick, are being figured at KPNO by the bend-and-polish method, and segment alignment controls are being developed at the U of C. U of Texas has been working on the design of a monolithic 7.6 metre telescope.

At the DAO, a light weight 3 metre telescope has been designed and is intended to operate either as a single telescope or in an array. Some of the passive mirror support units (which use flex pivots) have been made and are being tested using a small (30 cm) mirror having the same thickness and radius of curvature as the F/2, 3 metre, 24-1 meniscus primary mirror.

VI. NEW INSTRUMENTATION

Several new instruments are now in operation at the 6 metre BTA. At the Prime Focus: *a digital speckle interferometer* (ref. Yu.Yu. Balega, A. N. Kasperovich, Yu. A. Popov, N. N. Somov, A. F. Fomenko, Avtometriya (USSR) No. 3, 1980); a digital dissector photomultiplier for spectra and photometry with a photometric accuracy of up to 0.1% and a time resolution of 0.1 second; a slitless spectrograph with a transmission grating covering a field of 13 arcmin at dispersions of 1400 to 400 A/mm; a fast image tube spectrograph. At the secondary focus, the thermal stability in the fork tyne (where the spectrographs are located) has been improved, and the third Schmidt camera, F/1, is now in use.

At Steward Observatory a multi-object slit spectrograph has been built using fibres to align a field of images along the slit. The positioning of the fibres is being automated.

Observatoire de Marseille and Laboratoire d'Astronomie Spatiale du CNRS produced an F/1 focal reducer which has been used with the 6-metre BTA for observation of extended sources. Also, a "high space resolution integral field spectrograph" uses an array of lenses and fibre optics to give individual spectra of all 1" x 1" elements in the focal plane of large telescopes. A coronograph, similar to that of the space telescope, has been adapted to the Mont Chiran 1 metre and ESO 3.6 metre telescopes for the detection of faint features in stellar and planetary observations.

At ESO, a special reflectometer was constructed to measure the actual reflectivity and polarization of multilayer coatings (which can be different from that on the test pieces.) An echelle spectrograph was added to the coude of the 3.6 metre telescope in Chile, and a 3-element wide field corrector installed at the prime focus.

At KPNO, a cryogenic, F/1, CCD camera utilizing a grism element was added to the 4 metre spectrograph. A zero-deviating predisperser for optical bandwidth selection is now available, replacing filters, for the 1 metre Fourier Transform Spectrometer. At CTIO, image slicers were added to the coude spectrograph of the 1.5 metre telescope.

An infrared photometer was completed at Tartu Observatory in 1980. It measures in the four bands of the Arizona photometry and reaches stars as faint as 8.5 m at 2.2 μm with the 1.5 metre telescope. An infrared photometer for the 1.2-2.5 μm region was built for use on the Bjurakan 2.6 metre telescope. For the 10 μm region a heterodyne infrared detector of the University of Toronto will be used on the NASA 3 metre telescope in Hawaii.

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VII. SITE TESTING

An extraordinarily comprehensive site testing project is now under way in Saudi Arabia headed by E. Brosterhus, seconded from the Dominion Astrophysical Observatory, Canada. Four mountain sites are being tested simultaneously using automated seeing monitors run by four observers at each site.

VIII. PHOTO-ELECTRONIC IMAGE DEVICES

Report from the Working Group, W. Livingston, Chairman

Following tradition, reports have been solicited from Commission 9 members in an attempt to survey progress since the 1979 Montreal meeting. The pertinent efforts of almost a hundred workers thus came to our attention. Limitations in space force us to restrict this summary to information on devices and techniques that have been employed on telescopes post-Montreal. Furthermore, in the case of Charge Coupled Devices (CCDs) for example, only representative programs are described. For more detail than can be given here, and for the intriguing story of devices intended for space telescopes yet to be deployed, consult the following proceedings and reviews:

a) Electronography

At the Paris Observatory M. Duchesne and colleagues, benefiting from new laboratory facilities, now produce a variety of photocathodes (S1, S11, and S20) which are extremely uniform and efficient. G. Wlerick and B. Servan have used the 81-mm Lallemand Electronic Camera (EC) on the Haute Provence 1.9 m for direct observations of active extragalactic objects. Another E.C. is currently in operation on the 3.6-m CFHT. A detection of V = 25.2 m with a 4 σ certainty was achieved in an exposure of one hour by a group from Meudon.

Other recent EC activity includes that of M. Walker (Lick) and J. Andersen (Copenhagen), who have used the 80-mm McMullen camera on the 1.5-m at La Silla for B,V photometry of the Magellanic Clouds. In Flagstaff H. Ables and A. Hewitt [3] devised a new flat-fielding method for a Kron EC-improving their UBV standards program (11-22 m).

UV spectra in the 950-1800A region were obtained in 1980 by G. Carruthers, and collaborators, with his opaque CsI photocathode EC, transported by Aerobee rockets. He is currently testing a variety of novel UV EC for possible future space missions.

b) Image Intensifiers

At the Special Astrophysical Observatory (USSR) A. Afanasjev and A. Pimonov have installed a UM-92 3-stage magnetic reflector focus intensifier on an f/1.5 spectrograph of the 6-m reflector.

We note that at this time image intensifiers by numerous manufacturers, mainly products of the decade past, are the contemporary workhorses of astronomy. No new development work is reported. Presumably this is in deference to the promise of solid-state arrays, even though the latter have yet to be widely proven astronomically.

c) Solid State Arrays - CCD (Charge Coupled Device)

In the Fall of 1981 there is a dearth of commercially available CCDs; only RCA and Fairchild offer reasonable delivery times. A few experimental CCDs have been provided to astronomers including the Fairchild 720 x 244 pixels (proposed in Montreal), the GEC-UK 576 x 385, and the BNR 100 x 100. Other CCDs of very

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restricted availability are the Texas Instrument 800 x 800 and an array made in the Peoples Republic of China at size 64 x 64.

All the above arrays have been evaluated under actual astronomical conditions but since only the RCA chip is readily accessible, it is receiving the most attention. In fact some 23 different Institutes and Observatories report on its application.

The RCA 512 x 320 is a buried channel thinned device. Its advantages include (1) availability (2) an RQE (Responsive Quantum Efficiency) > 70% from 4000-8000A and (3) relative insensitivity to cosmic rays. Disadvantages are (1) fringing at a level of 5 to 20% modulation (2) a low-light level charge-transfer failure and (3) a readout noise of 50-80e. Fringing, or the presence of wavelength dependent, pixel dependent, channel spectra is a particular problem. Depending on the application fringing may set the performance limit. In general all CCD's suffer at some precision level from fringing, and our ability to adequately flat-field the device worsens as the detector excels photometrically, as discussed recently by W. Baum [4].

Astronomically the productive use of the RCA chip has been demonstrated by B. Oke (Palomar Obs) [4] on the Cass. spectrograph of the 5.1m telescope and by J. Geary and D. Latham on the 4.5-m MMT [4].

The TI (Texas Instrument) 800 x 800 has been operated in Kitt Peak's cryogenic camera. Mounted on the 4-m spectrograph with an f/1 Schmidt, a resolution of 15A is achieved from 4800-11000A in 5 steps with interchangeable grisms. In place of a single slit a custom aperture plate permits the simultaneous observation of up to 20 objects, each accompanied by adjacent sky (H. Butcher). Some loss of resolution is found because the thinned TI chip is not flat but rather "crinkled" ±.05 mm.

d) Solid State Arrays - CID (Charge Injection Device)

Both the GE-USA 100 x 100 and 244 x 248 CID have been pushed to a precision limit for high light level applications in solar spectroscopy by J. Harvey, (Kitt Peak), T. Duval Jr., (NASA), and E. Rhodes, (Univ. S. California). A solar line which spans about 40 pixels can be centroided to about 1/1000 of a pixel for a 1-minute observation. This corresponds to a velocity uncertainty of 25 cm s^{-1}.

e) Solid State Arrays - "Reticon" Type (Array of self scanned diodes.)

Self-scanned diode arrays are commonly found on coude spectrographs these days - 11 observatories indicating their current use. The Reticon has a wide band of response from atmospheric cut off (2950A) to about 10000A. The red RQE is temperature dependent though not markedly so. S. Vogt (Lick) finds the device response down only 50% at 1.0 micron when cooled to -130^{o}C. He presents in ref. 4 a nice set of examples of 1 x 1872 Reticon spectra ranging from CaII H and K (S/N ≈ 100 in 34^{m} exposure, $\Delta\lambda$ = .36A, V = 4.7 m, 56 Peg) to Fe H at 10057A (S/N = 114 in 20^{m}, $\Delta\lambda$ = 1.4A, V = 10.3 m, EV Lac).

At the University of Texas R. Tull continues to implement the use of Reticons with 5 systems deployed on coude and Cass spectrographs.

The new Mark-III K-coronameter on Mauna Loa utilizes a 1 x 512 Reticon allowing coronal transients to be seen for the first time from the ground (R. Fisher, High Altitude Obs).

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f) Solid State Arrays - Infrared

Array devices for wavelengths longward of 1 micron have been under development for more than a decade but only now are appearing on telescopes. F. Sibbille (Lyon and Meudon), with the engineering assistance of F. Gillette (Kitt Peak), have used a 32 x 32 InSb CID GE-USA on the KPNO 2.1 m for the speckle observation of IR source diameters. The array suffers some lag (i.e., suffers from residual image) and is probably system noise limited even at full well (i.e., when saturated). But it is sensitive at 2-3 microns and suitable for speckle.

Another forerunner of arrays to come is a 32 x 32 Bi-doped Si CID made by Aero-Jet. J. Arens (Goddard) and W. Hoffmann (Steward) have successfully used the array in the 12 micron window for mapping the Kleinmann-Low Region in Orion.

g) Image Photon Counting Systems - IPCS

Ten observatories report the more-or-less routine operation of an IPCS. The IPCS is customarily a hybrid device which can be made up of quite varied components.

The Laboratoire d'Astronomie Spatiale and the Obs. Marseille have constructed a 512 x 512 IPCS consisting of an MCP (micro channel plate -- not male chauvinist pig) + SIT (silicon intensified target) manufactured by Thomson (UK), G. Courtes, B. Fort, J. Boulesteix, et al., have regularly used this instrument on both the 1.9 m (Haute Provence) and the 6.0 m (Zelenchukskaya), mostly for direct narrow band work.

At the Special Astrophysical Obs (Zelenchukskaya), I. Balega et al. have in operation a 2 x 500 IPCS consisting of the "UM-92" plus a supersilicon (Vidicon-type) tube. It has seen service on the f/1.5 spectrograph of the 6 m telescope. Centroiding is employed [5].

Other new and interesting systems include the Mount Stromlo-Siding Spring 760 x 480 IPCS (a 25 mm MCP + Fairchild CCD). Centroiding effectively doubles the detector resolution, T. Stapinski, et al.

After many years of effort by J.G. Timothy the Multianode Array (MAMA) is showing astronomical results. Collaborating with J. Linsky and others the MAMA has produced excellent high resolution spectra in a search for stellar magnetic fields. The work continues on the 1.6 m McMath.

A system which allows the speckle interferometry of objects as faint as V = 16 m has been installed on the Steward 2.3 m (E. Hage et al.). A 4-stage Varo intensifier coupled to a "Plumbicon" television camera tube produce near saturated video single photoelectron events [3].

h) Electronography vs CCD vs IPCS, etc.

The variety of image detectors being pursued remains large and in some ways bewildering. But each device has its own strength and suitability for a class of observational problems. For example one might think for faint object spectroscopy a TI 800 x 800 CCD (Gunn and Westphal) with its RQE > 50% and noise < 10e might be superior to an IPCS (e.g. Boksenberg; 4-stage EMI + Plumbicon) with RQE $\sim$ 10%. If the object sought is an emission line QSO it requires only a few detected photoelectrons to define each line, and then the wavelengths of many lines may be averaged to obtain a reliable red-shift. In this instance the IPCS wins easily over the CCD. However, if it is a matter of absorption line detection the CCD may be the choice. We note, too, that the limiting magnitude of 26.0 reached via the

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CCD (Gunn and Westphal [4] is similar to 25.2 attained by electronography (Picat, et al. [5]. Seeing is no doubt a factor here.

i) Software Development

Practically every instrument mentioned in this report is computer intensive in practice. That is, each device imposes, pixel by pixel, a photometric signature of dark current, wavelength-dependent gain and possibly linearity. To the extent that these variables are constant with time the incident astronomical image can be recovered through proper flat fielding while data taking, and then rectifying the errors by computer manipulation. Evidently the better the device photometrically, the more subtle the corrections become and, ironically, the more difficult the task. C.R. Lynds has remarked that for reasons unknown, perhaps unknowable, an early version of the CCD (the Fairchild 190 x 244) had superior photometric properties not found in recent devices. It was linear to well below the threshold noise level of $\sim$ 15e. The bias produced by single electrons can be noticed at low spatial frequencies. See also the comments of D. Monet (Mt. Wilson Obs) [4].

C.R. Lynds and associates at Kitt Peak are developing sophisticated algorithms to rectify Space Telescope Wide-Field Camera CCD data. J.A. Tyson (Bell Labs), C. MacKay (Cambridge), W. Baum (Lowell), and many others report extensive work peculiar to their astronomical objects and receptors.

A video camera/CCD standards consortium has been established (C. Christian, CFHT).

All of the above efforts should benefit from cooperation, preferably on an international scale.

REFERENCES

Ref. 1. Ford Jr., W.K.: 1979, "Digital Imaging Techniques" in Ann Rev A A **17**, pp. 189-212.

Ref. 2. "Cryogenically Cooled Sensor Technology", Proceedings of Conference in San Diego, 29-30 July 1980, Proc Soc Photo-Opt Instr Eng (SPIE) **245**, R.J. Huppi, ed

Ref. 3. "Applications of Digital Image Processing to Astronomy", Pasadena, 20-22 August 1980 SPIE **264**, D. Elliot, ed

Ref. 4. "Solid-State Imagers for Astronomy, Cambridge, Mass., 10-11 June, 1981, SPIE **290**, J.C. Geary and D.W. Latham, eds (SPIE publications can be obtained from SPIE, P.O. Box 10, Bellingham, Washington 98227, U.S.A.)

Ref. 5. "IAU Colloquium No. 67, Instrumentation for Large Telescopes", Zelenchukskaya, 8-10 September, 1981.

IX. HIGH ANGULAR RESOLUTION INTERFEROMETRY

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

a) Introduction

The following report has been based mainly on replies received to a circular letter sent to all groups and workers known to be active in the field of high angular resolution interferometry.

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The proceedings of I.A.U. Colloquium No. 50 "High Angular Resolution Stellar Interferometry", held at the University of Maryland in August, 1978 have been published (1). Sessions on interferometry have been included in several meetings recently indicating a growing awareness of the potential of this field now that modern technology promises the ability to overcome the problems that have restricted its progress. An example was the discussion of interferometric techniques and their application to binary star studies in sessions organized by H. McAlister at I.A.U. Colloquium No. 62 (Flagstaff, May 1981).

b) Speckle Interferometry and Image Reconstruction

i) Speckle Interferometry. A decade has now passed since Labeyrie (2) invented speckle interferometry, a technique that uses short-exposure images to achieve diffraction-limited angular resolution from Earth-based telescopes. There are currently at least eight groups who have built or are building instruments for visible-light speckle interferometry. The following list gives their locations and names of representatives of each group: CERGA, France (Labeyrie), Erlangen-Nurnberg University, Germany (Weigelt), Georgia State University, U.S.A. (McAlister), Harvard University, U.S.A. (Nisenson/Stachnik), Imperial College, U.K. (Morgan), Kitt Peak National Observatory, U.S.A., Steward Observatory, U.S.A. (Hege/Strittmatter), University College, U.K. (Boksenberg).

The most significant instrumental development has been the use of photon counting methods of image recording and real time analysis. For several years, theoretical studies predicting limiting magnitudes in the range m_V = 18-20 have been viewed sceptically by many observers. Recently, Arnold et al. (3) and Hege et al. (4) have reported measurements on Pluto and QSO PG 1115+08 respectively at m_V = 16; the latter observations are of particular topical interest, since gravitational lens theory predicts another, as yet unresolved, component of this "multiple" quasar. Morgan et al. (Imperial College) have constructed a fast, vector autocorrelator for on-line analysis of photon-counting data which has several display modes to aid interpretation as data are being taken. The Harvard group currently uses videotape as an intermediate storage medium and is developing a novel photon event counting detector system that records the space and time co-ordinates of detected photons. Aime et al. (5) have made systematic measurements of the transfer function of speckle interferometry.

ii) Image Reconstruction. Progress on image reconstruction has been concentrated in three areas; extending the technique of speckle interferometry, new interferometric techniques and adaptive optics. Fienup (6) has shown, using computer simulations, that the modulus of the object Fourier transform alone can sometimes be sufficient to reconstruct a map of the object; the plausibility of this result is discussed by Bruck and Sodin (7), but the uniqueness is disputed by Huiser and van Toorn (8). For certain special cases, for example when there is a reference star in the field, speckle holography (9) can yield a map of the object.

Image reconstruction based on only the modulus of the object's transform has the advantage that it directly utilizes the output of Labeyrie's speckle interferometry. Slightly less convenient, but still not requiring any optical processing or special interferometers, are methods in which the speckle data (shortexposure images) are processed in an alternative way; two examples are the methods of Lynds et al. and Knox and Thompson. Bates and Cady (10) have extended the method of Lynds et al., coining the description "shift and add"; this method is based on the assumption that the brightest speckles are noisy images of the object. Nisenson and Stachnik (11) have implemented their extensions of the Knox-Thompson algorithm.

Another approach to using interferometric data is to optically preprocess the image prior to detection - heterodyning is one possible example. Walker (12) has

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drawn attention to a method first proposed by Mehta. Roddier et al. (13) and Roddier and Roddier (14,15) have described how rotation shearing interferometry can yield diffraction-limited images of stellar objects.

Adaptive optical techniques can also be used for diffraction-limited imaging, although they are fundamentally limited to relatively bright objects. Hardy (16) describes the performance of a 21-zone device at Sacramento Peak Observatory on both compact and extended sources. At the moment, the cost of such systems precludes their use in astronomy.

c) Infrared Interferometry

An improved version of the one-dimensional speckle technique has been developed by D.W. McCarthy and F.J. Low at the University of Arizona for spatial interferometry in the infrared. The image of a star or galaxy, produced by a large telescope, is scanned rapidly across a single narrow detector. The resulting signal is analysed to produce accurate and repeatable one-dimensional visibility functions. Data from 2 to 12 µm have been obtained at the Steward Observatory 2.3 m telescope for a variety of stars with circumstellar envelopes including a number of protostellar objects such as Mon R2 and W3. In collaboration with F. Gillett of KPNO and S. Kleinman of MIT the 4 m telescope has been used to partially resolve the nucleus of the bright Seyfert galaxy NGC 1068. These data, at 2.2 µm and 3.4 µm, show the existence of a bright nuclear core of diameter less than 0.1 arcsec.

A 10 µm heterodyne interferometer has been employed for astrometric tests by E. Sutton, S. Subramanian and C. Townes, using McMath telescopes at Kitt Peak. With a baseline of 5.5 m, a night to night precision of 0.08 arcsec rms was obtained for the angular separation of stars as large as 50 degrees. These small variations are primarily due to the mechanical instability of the telescopes and not to atmospheric causes.

d) Visual Long Baseline and Multi-Aperture Interferometry

There are three groups actively working at developing long baseline interferometers for operation in the visual part of the spectrum. These groups are based at the University of Sydney (Hanbury-Brown and Davis), at the University of Maryland (Currie) and at CERGA, France (Labeyrie).

The Sydney group are developing an 11 m baseline prototype of Michelson's stellar interferometer (17) in which the aperture size is restricted to select essentially flat portions of the wavefront, wavefront tilts are removed by active optical components and rapid sampling of the interference removes the effects of randomly varying phases. In June 1981 the siteworks and housing for the prototype were nearing completion and installation of the component parts of the interferometer was planned to commence towards the end of 1981. The prototype is the first stage in the planned development of a major instrument with baselines up to ∿ 1 km.

The Maryland group, led by Currie, are also developing a prototype instrument, which has been described by Liewer (1), based on their amplitude interferometer (18). The prototype has a baseline of ∿ 3 m oriented parallel to the Earth's rotation axis and is being installed at the optical research facility of the Goddard Space Flight Center. This instrument is designed to work at baselines up to 50 m when installed at a permanent observing sight. Currie has also continued the development of the multi-aperture amplitude interferometer which he ultimately intends incorporating in the long baseline interferometer.

At CERGA work has continued with the prototype long baseline interferometer

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(19) which employs 26 cm aperture telescopes and baselines in the range 5 to 35 m. Efforts to improve data acquisition and analysis have been reported by Koechlin and these are anticipated to lead to improvements in accuracy of angular diameter measurements to the order of 5%. Labeyrie has continued his programme to develop a large aperture synthesis array (20) and the first 1.5 m aperture telescope with novel concrete housing has been installed and has undergone extensive tests on its unusual drive system. It is planned to assemble a second telescope and operate the pair as a long baseline interferometer with baselines up to 60 m in the first instance.

Shao and Staelin of MIT have successfully tested a prototype 1.5 m baseline phase tracking stellar interferometer. Continuous fringe phase and amplitude measurements have been made using 1.27 cm apertures under 2 arcsec seeing conditions for Polaris (21). These preliminary measurements show that 8.7 to 10 magnitude stars should be observable with two 12.5 cm aperture telescopes. A 3 m baseline phase tracking stellar interferometer for astrometry is currently under development. This instrument will have 5 cm apertures and a field of 1°.

e) Interferometry from Space

Several workers have carried out preliminary investigations of possible high angular resolution interferometers for operation above the atmosphere. These include Currie (Maryland), Hammerschlag (Utrecht), Kibblewhite (Cambridge, UK), Labeyrie (CERGA) and Stachnik et al. (Cambridge, USA)

As an example of the results of this type of study, Stachnik reports that he and his colleagues have found that the technology for a 10 km baseline system consisting of two one-metre telescopes and a central station for fringe measurement, while different from that required for a monolithic device with a baseline of tens of metres, is not notably more complex. Whether monolithic or detached, a long baseline space interferometer would be an active optical system requiring precision location and positioning of the optical elements. Combining existing spacecraft precision location, pointing and ranging technology with low thrust-high efficiency electric propulsion systems, a judicious choice of orbits and an appropriate fringe search algorithm makes baselines of many kilometres quite plausible. Specific conclusions of this study are that (i) 10^{-5} arcsecond resolution is possible; (ii) for circular 1000 km equatorial orbits differing slightly in inclination, the central station remains within 5 mm of optical pathlength equality during the first orbit, with no expenditure of fuel, while the 10 km baseline is repeatedly scanned; (iii) existing ranging, pointing and tracking technology are adequate, even without use of a ranging interferometer, to predict the location of the stellar fringes to within 1 cm over the 10 km baseline; (iv) a combination of an electric propulsion system consisting of four gimballed thrusters and an on-board optical delay line would permit fringe acquisition within the 1 cm region for sources as faint as m_V = 15 to 18.

f) Scientific Importance of High Angular Resolution at Infrared and Optical Wavelengths

A conference entirely dedicated to this subject was held by ESO at Garching March 24-27, 1981, at which it was very strongly emphasized that optical resolution equivalent to that obtained by the VLBA at radio wavelengths will be essential for future progress. With a baseline of the order of 300 metres objects as faint as magnitude 20 could be observed in an hour with a 300A bandpass with a resolution of 0.3 milliarc seconds at 5000A. With instruments of this type the broad line region in Seyfert Galaxies could be resolved (M. H. Ulrich) as well as highly compact structures in galactic nuclei and quasars (M.J. Rees). A proposal for realizing such an instrument at minimum cost was given by G. Odgers, namely to combine the 3.8 metre UKIRT and the 3.6 CFHT on Mauna Kea giving an interferometer

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of 350 metre baseline. The envelopes of protostars could be observed with this resolution (N.W. Yorke) as well as stellar winds and chromospheres (F. Schatzman) and star formation itself (P.A. Strittmatter). An interferometer for space was proposed by A. Labeyrie which would have a baseline of 200 metres, resolution of 0.1 milliarcsec, limiting magnitude of 26, with 1 metre mirrors. A very long baseline (10 km) intensity interferometer was proposed by D. Dravins. Such an instrument could observe very bright objects with an angular resolution of approximately 10^{-5} arcseconds. It would be possible to detect fine structure of stellar surfaces.

REFERENCES

1. "High Angular Resolution Stellar Interferometry" (I.A.U. Colloquium No. 50),ed. J. Davis and W.J. Tango (Chatterton Astronomy Department, School of Physics, University of Sydney), 1979.
2. Labeyrie, A.: 1970, A & A **6**, 85.
3. Arnold, S.J., Boksenberg, A., and Sargent, W.L.W.: 1979, Ap J **234**, L159.
4. Hege, E.K. et al.: 1981, Ap J **248**, L1.
5. Aime, C. et al.: 1979, Optica Acta **26**, 575.
6. Fienup, J.R.: 1978, Opt Let **3**, 27.
7. Bruck, Yu M. and Sodin, L.G.: 1979, Opt Commun **30**, 304.
8. Huiser, A.M.J., and van Toorn, P.: 1980, Opt Lett **5**, 499.
9. Weigelt, G.: 1979, Optica Acta **26**, 1351.
10. Bates, R.H.T., and Cady, F.M.: 1980, Opt Commun **32**, 365.
11. Nisenson, P. et al.: 1980, Proc SPIE **243**, 88.
12. Walker, J.G.: 1981, Optica Acta **28**, 1017.
13. Roddier, C. et al.: 1981, Conf Proc ESO, Munich.
14. Roddier, C., and Roddier, F.: 1981, Conf Proc ICO, Graz.
15. Roddier, F., and Roddier, C.: 1981, Conf Proc IAU Coll No. 67, Zelenchuk, USSR.
16. Hardy, J.W.: 1981, Proc Conf ESO, Munich.
17. Davis, J.: 1979, New Zealand J Sci **22**, 451.
18. Currie, D.G., Knapp, S.L., and Liewer, K.M.: 1974, Ap J **187**, 131.
19. Labeyrie, A.: 1975, Ap J **196**, L71.
20. Labeyrie, A.: 1978, Ann Rev A A **16**, 77.
21. Shao, M., and Staelin, D.H.: 1980, Appl Opt **19**, 1519.
22. Ulrich, M.H. 1981 Conf Proc ESO Munich
23. Rees, M.J. 1981 Conf Proc ESO Munich
24. Odgers, G.J. et al. 1981 Conf Proc ESO Munich
25. Labeyrie, A. 1981 Conf Proc ESO Munich
26. Dravins, D. 1981 Conf Proc ESO Munich

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