9. INSTRUMENTS AND TECHNIQUES (INSTRUMENTS ET TECHNIQUES)

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I. MEETINGS, SYMPOSIA, AND GENERAL COMMENTS

Between the Patras and New Delhi General Assemblies no meetings were directly sponsored by Commission 9 because the discipline was amply covered by the following:

- "Eighth Symposium on Photoelectronic Image Devices," Imperial College (London) 5-7 September 1983 (B. L. Morgan, Ed., Academic Press, London, 1984).

- "Advanced Technology Optical Telescopes II" Imperial College, 5-7 September 1983.

- "Instrumentation in Astronomy V" 7-9 September 1983 (A. Boksenberg and D. Crawford, Eds., Proc. SPIE 445).

- IAU Symposium No. 109: "Astrometric Techniques," 9-12 January 1984, Gainsville (Florida).

- "Astronomical Photography 1984," Edinburgh, 4-6 April 1984 (E. Sim and K. Ishida, Eds., Number 14 of Occasional Reports of the Royal Observatory, Edinburgh).

- "IAU Colloquium No. 79: "Very Large Telescopes, Their Instrumentation and Programs," Garching bei München, 9-12 April 1984 (M. H. Ulrich and K. Kjär, Eds.)

Following the New Delhi General Assembly a large turnout is expected at:

- IAU Symposium No. 118: "Instrumentation and Research Programs for Small Telescopes," Christchurch, 2-6 December 1985.

Our report period, 1981-84, covers many advances in astronomical instruments. Outstanding was the success of the Infrared Astronomical Satellite, a 57-cm aperture telescope cooled to 2-5 K permitting high resolution mapping of the entire sky to a wavelength as long as 100μm. Perhaps most significant to the ground-based astronomer has been the pervasive application of CCD detectors. Now even small instruments can tackle problems that formerly were the reserve of the great telescopes. Of course the efficiency of large aperture instruments has likewise soared, particularly through the techniques of multi-object spectroscopy. No longer are galaxies observed one at a time but rather 50 to 100 are simultaneously recorded via, for example, fiber optic feeds. A system planned for the Special Astrophysical Observatory 6-m telescope will accommodate up to 500 objects.

Several very large telescopes in the 7m+ class are being planned. Some are even financed! Particularly noteworthy toward such endeavors is the large mirror casting facility being developed by R. Angel and colleagues at the University of Arizona. Seldom before have astronomers proven so self-reliant.

Spatial interferometry and solar/stellar oscillations are two subjects that have blossomed during the past three years. The promise of this new generation of large aperture telescopes is especially favorable for speckle, both in the visible and IR. The possibility of probing to the very centers of the sun and stars by observing a periodic surface heaving a few cm s^{-1} in amplitude was unthinkable a decade ago. We are fortunate to have received and included comprehensive reports on interferometry by John Davis and oscillation techniques by Jack Harvey.

We can recognize a new trend in instrument design whereby the relatively inexpensive "microprocessor" becomes central to instrument control, and assuming the role formerly occupied by large computers. The latter may still be essential to data gathering, but not at the operational level.

One dream of the telescope makers is proving very difficult to realize: the restoration of images (as distorted by atmospheric seeing) through the use of active optics. Several talented people are working on this problem but so far the atmosphere has not cooperated. Perhaps high resolution imagery will prove ultimately to be the domain of space telescopes.

II. FUTURE VERY LARGE TELESCOPES
J. Beckers

Many countries are planning large ground-based telescopes for visible and infrared astronomy. This renaissance in large ground-based telescopes is at least partly due to the development of new technologies related to telescope control, telescope buildings, and mirror making. Innovations in these areas, as well as the rapid increase in the use of computer control of telescopes and instruments, have increased the capabilities of telescopes while often reducing the cost.

The European Southern Observatory will build a 3.50-m New Technology Telescope (NTT) in Chile which uses a relatively thin (1:15) low expansion glass or, possibly, a metal mirror blank. It also has plans for a Very Large Telescope (VLT), consisting of an interferometric array of four 8-m aperture telescopes. Great Britain plans to dedicate shortly its 4.2-m Herschel Telescope in the Canary Islands. The Royal Greenwich Observatory is developing a plan for a multiple mirror type telescope using six 7.5-8-m mirrors and plans for an interferometric array of large telescopes are being studied at the Royal Edinburgh Observatory. Iraq will acquire a 3.5-m telescope, identical to the German Calar Alto Telescope in Spain. The Tokyo Astronomical Observatory in Mitaka, Japan, has submitted a proposal to the Japanese government for a 7-8-m telescope to be built on Mauna Kea. In the United States the University of California and the California Institute of Technology are well along the way with the planning and funding of a 10-m aperture segmented mirror telescope (TMT) to be placed on Mauna Kea. The University of Texas is proposing a 300-in. telescope to be located at or near the McDonald Observatory. A consortium of universities (Princeton, Chicago, Washington State and New Mexico State) will shortly start construction of a 3.5-m aperture telescope in the Sacramento Mountains of New Mexico. The National Optical Astronomy Observatories is proposing a Southern Optimized IR Telescope to be located at Cerro Tololo, Chile. It is also now working on the final design and proposal for the National New Technology Telescope (NNTT), which will be of the multiple mirror kind having four 7.5-m diameter mirrors. Sites on Mauna Kea and Mt. Graham (Arizona) are being tested for its location. In the USSR a 5-m class telescope is being considered by the Leningrad University to be located in Central Asia. The Crimea Astrophysical Observatory is developing plans for a 25-m aperture segmented mirror telescope to be built at an, as yet, undefined location.

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III. SOLAR TELESCOPES
O. Engvold

At the Canary Islands, three interesting new solar telescopes are nearing completion.

A 60-cm Vacuum Tower Telescope of the Kiepenheuer-Institute, Freiburg, is expected to be operational at the Izaña site in the summer of 1986. The feed system is a classical 80-cm coelostat on top of a 38-m high, double walled concrete tower. An auxiliary telescope system uses a fraction of the main aperture and forms a full disk image of the Sun for tracking. Piezoelectric-driven tilting of the second coelostat mirror is used to correct tracking errors and stabilize the main solar image. This telescope will be equipped with a multi-channel slit-jaw camera unit. There is also a large, grating spectrograph to be outfitted with a French Multi-channel Subtracting Double Pass (MSDP) arrangement. Italian solar astronomers will provide a narrow band, wavelength stabilized, universal filter.

A 40-cm Gregory-Coude vacuum tower telescope of Göttingen University, will be operational at Izaña by June 1985. This telescope was earlier at the German station at Locarno, and it has been refurbished for the installation at the new site.

Finally, the solar telescope of the Swedish station at La Palma is being reconstructed and is expected also to be operational in summer 1985. An alt-azimuth turret at the top of a 16-m high tower will feed an f/45 50-cm achromatic objective lens which at the same time serves as entrance window for the vacuum system.

In addition there is the large French telescope "Telescope Heliographique pour L'Etude du Magnetisme et des Instabilites Solares" (THEMIS) which has been designed for accurate polarization measurements of the Sun. It will have a 90-cm Ritchey-Chretien telescope feeding a solar magnetograph. THEMIS is planned for the Izaña site.

An open solar telescope with emphasis on stability is being developed in Utrecht. Its construction could be finished by the end of 1985, and the telescope might possibly be erected at La Palma.

A 35-cm aperture solar telescope-magnetograph is being developed by the Nanjing Astronomical Instrument Factory for the Beijing Observatory. This telescope has a refractive imaging system with a doublet objective that gives a 4x6 arcmin^2 field-of-view. The polarization measuring system is made up of a KD*P modulator and specially designed narrow band birefringent filters.

The design study of the Large European Solar Telescope (LEST) has been completed. A 2.4-m Gregorian-type telescope with an additional ellipsoidal mirror provides a 20-arcmin diameter diffraction limited field-of-view. Two flat mirrors reflect the light out and along the elevation and azimuth axes of the telescope mounting so that the final image is fixed (except in rotation about its center) with respect to its auxiliary instruments. These will be located near the bottom of a 25-m high double concrete tower. A thin entrance window seals the telescope light path which will be filled with helium gas. The aim is a telescope planned for high spatial resolution and low instrumental polarization measurements. The detailed design of the telescope will be complete in 1-1/2 to 2 years. *By the end of 1984 the following countries have joined the project:* FRG, Israel, Italy, Norway, Sweden, Switzerland, and Australia.

At the Baikal Astrophysical Observatory in the Soviet Union, the construction of a large solar vacuum telescope is nearing completion. This telescope has a 76-cm doublet objective 760 with a focal length of 40 m that is fed by a siderostat 100 cm in diameter. The siderostat is placed atop a 20 m tower on the steep slope of a mountain. A vacuum tank of 40-m length comes down to the foundation of the tower along the polar axis. This tank includes the objective lens in the upper part and a diagonal flat mirror that directs the light beam horizontally onto the spectrograph slit. The vacuum tank is closed from above and below by optical windows 100 cm in diameter. Outside the lower window the solar image is fed to a photoelectric guiding and scanning carriage, while the diagonal mirror directs a minor portion of the solar image onto the slit. The telescope optics and optical windows are now installed, and the tank can be evacuated as low as 10 mm. Investigation of the optical and thermal properties of the entrance window are underway. White-light pictures at the Newtonian focus are being taken. Construction of a spectrograph and other auxiliary instruments is also well along.

At the Sayan Solar Observatory a modernization of the horizontal solar telescope is completed. A new coelostat mounting with mirrors 80 cm in diameter are installed. The 80-cm primary of the telescope has a focal length of 20 m.

The first attempt to achieve high spatial resolution of a solar image for extended periods (more than 80 hours) is to be made from a NASA satellite scheduled for launch in July 1985 as Spacelab II. A Lockheed Research Laboratory instrument called a Solar Optical Universal Polarimeter (SOUP) and having a 30-cm aperture, is intended to map solar magnetic fields in visible light and to study their evolution to 1/2 arc-sec. While this resolution has been obtained occasionally on the ground, the significant aspect is that resolution is expected to be constant during the entire flight. Complementing this is the Naval Research Laboratory High Resolution Telescope Spectrometer (HRTS) which maps the transition region redward from Ly α at a similar spatial resolution.

IV. OTHER NEW INSTRUMENTATION

Limitation of space does not permit a full listing of all the new and planned instrumentation that has come to the attention of Commission No. 9. We therefore mention only a sampling.

- In India, at Kavalur, a 2.3-m reflector is nearing completion by the Indian Institute Astrophysics. This telescope was fathered by Vainu Bappu, former President of the IAU.

- In Argentina a 2.15-m Boller and Chivens Reflector, purchased in 1970, is now being installed by Compeljo Astromico "El Leonitio."

- In the Peoples Republic of China, a 1.56-m Cervit reflector will begin operation next year in a suburb of Shanghai.

- On the southwest ridge of Kitt Peak a 2.4 m reflector of the McGraw-Hill Observatory expects first light in June 1985.

- At Siding Spring, Australia, a new 2.3-m "Multiple-mirror-telescope/ advanced technology telescope," is now operational. Innovations include a rotating domeless building similar to Arizona's MMT.

- A multi-slit spectrograph is being developed for the 6-m Zehelchuk, Special Astrophysical Obs., that allows the simultaneous observation of 500 objects.

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- A 24 element segmented active mirror with phase correction is being tested by Robert Smithson for seeing correction at the Sac Peak Vacuum Tower.

- The National Optical Astronomy Observatory continues to support a Gratings Laboratory built around the MIT "C" engine. Mounted on a vibration isolated slab and temperature controlled to ~ .003 C, a variety of unique gratings have been produced. Three attempts have been made at a 300x400-mm, 632 groove-mm^{-1} ruling for solar work. The machine improvements that followed from these attempts make the venture still promising. When success is realized replicas of the sub-master will be available to astronomical community.

- A new focal reducer (f/15 to f/8) has been developed by G. Courtes at the Observatoire de Haute Provence in order to obtain an 18 arc-min field with the 80-mm Lallemand-Wlerick electronic camera. This focal reducer is equipped with two spectrographic modes, 1500A mm^{-1} and 40A mm^{-1} multislit and slitness combinations.

V. PHOTOGRAPHIC PROBLEMS
Report by the Chairman of the Working Group, E. Sims

The principal activity of the Working Group in the period under review was the meeting held in Edinburgh, Scotland, from April 4 to 6, 1984. About 40 papers and posters were presented to 65 participants from 16 countries. Topics ranged from the nature and behaviour of emulsions through their use at the telescopes and in the laboratory, to the use of photographic and machine based techniques for rapid extraction of information from original photographs.

Highlights of the meeting included a discussion on the possibility that a new technique of emulsion manufacture which can control the morphology of the light-sensitive grains ("T-grains") may be applicable to spectroscopic emulsions. If this proves to be possible, it may lead to a new technology emulsion with a significant improvement in speed/grain characteristics over the present IIIa-J and IIIa-F emulsions. The problem of the occurrence of microspots on processed IIIa-J plates was discussed at length, but it is clear that we do not yet understand the cause of this problem. Several papers described specially designed photographic laboratories and some of the techniques used in them to make information from the original plates more widely or more readily available, such as unsharp masking and image enhancement. Descriptions and reports were given of some new, and not so new, fast measuring machines (including three PDS machines and COSMOS) and their ability to produce high quality photometry, astrometry and spectrophotometry from measurements of large photographic plates. There was general agreement that a good, atlas-quality copy of an original plate can be as reliable and useful as the original plate for any of these applications. During the period of the meeting a conducted tour of the Royal Observatory, Edinburgh included visits to the Plate Library, housing all the UK 1.2 metre Schmidt photographs, the COSMOS measuring machine, and the extensive Photographic Laboratories.

Also of interest to astronomical photographers was IAU Colloquium number 78, "Astronomy with Schmidt-type Telescopes" (Asiago 1983). At that meeting the following Resolution was passed:

Participants in the IAU Colloquium number 78: "Astronomy with Schmidt-type Telescopes," in concordance with the IAU Commission 9 Working Group on Photographic Problems acknowledging the impressive advances during the past decade resulting from the introduction of new emulsions of increased sensitivities, and over a wide spectral range, and recalling the continued interest in our science shown by several manufacturers of photographic materials, in particular the

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Eastman Kodak Company, and noting the continuing and growing need for photographic emulsions in support of both ground-based and space astronomy, especially with wide-field, high resolution sky survey telescopes for which it is unlikely in the near future that panoramic electronic detectors will have the detector size and resolution available on photographic materials, urge all manufacturers to initiate and continue research with the aim of providing new emulsions with improved characteristics - for example quantum efficiency, sensitivity and spectral range."

In response to this Resolution, Mr. L. J. Thomas, Senior Vice-President of Eastman Kodak Company and Director of Kodak Research Laboratories, replied to the General Secretary (25 October, 1983) with the following encouraging letter:

"Eastman Kodak Company is proud of its long association with the astronomical community. Improved plates have continued to be developed such as the introduction in the 1970's of KODAK spectroscopic plates Type IIIa-J and Type IIIa-F, based on the percepts of Marchant and Millikan. Also, Kodak's research effort as reflected by the papers of James, Lewis, Babcock et al. on the reduction of low intensity reciprocity failure in model systems, the $AgNO_3$ hypersensitization of KODAK Spectroscopic Plate, Type IV-N, by Jenkins and Farnell; the continuing participation by a member of our scientific staff in both the AAS and IAU photographic working groups; and the corporate support of the new Palomar Sky Survey in concert with the Alfred Sloan Foundation and the National Geographic Society are important roles for Kodak.

I believe you are aware of the recent introduction in the color negative and medical X-ray markets of films which utilize a new emulsion technology employing silver halide crystals of specific morphology that we refer to as "T-grains". Our research laboratories intend to explore the possible application of this new emulsion technology to astronomical photography. Although it is not prudent to anticipate in specific terms the results of research not yet complete, we share your hope that the work will lead to advances useful in photographic astronomy."

In the Soviet Union a new high speed infrared film with a maximum sensitivity at 10600A is available. Sample tests at the Crimean Observatory by Scherbakova indicate a sizable gain over Kodak IZ. The film does not need to be hypersensitized.

VI. HIGH ANGULAR RESOLUTION INTERFEROMETRY
Report by the Chairman of the Working Group, J. Davis

a) Introduction

The following report has been based 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. The assistance of F. Roddier in preparing the section on speckle interferometry and image reconstruction is gratefully acknowledged.

The interest in high angular resolution interferometry and its potential astronomical applications has increased significantly with several meetings including sessions on interferometry in their programs. These include IAU Colloquium No. 62, "Current Techniques in Double and Multiple Star Research," IAU Symposia Nos. 109 and 111, "Astrometric Techniques," and "Calibration of Fundamental Stellar Quantities," and a combined IAU-URSI symposium on "Indirect Imaging" [1]. The Optical Society of America included a symposium on Michelson spatial interferometry in its 1982 annual meeting and there have been a number of workshops held on various aspects of the subject.

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b) Speckle Interferometry and Image Reconstruction

Major reviews of speckle interferometry and image reconstruction have been published by Bates [2] and Dainty [3]. As noted by Dainty, observational speckle interferometry is now over a decade old and some 80 papers primarily concerned with astronomical results have been published. Examples of its applications include the study of binary stars where it has produced a wealth of data. It has also been used in studies of Pluto and its moon Charon, to determine the dimensions of asteroids and to study solar granulation. In extragalactic studies one of the components of the "triple" quasar PG 1115+08 has been resolved as a binary and new limits on fine structure of the nucleus of the Seyfert galaxy NGC 1068 has been obtained in the visual and in the IR.

Extension of speckle interferometry to the IR has led to the detection of unseen companions to nearby stars. A method of exponential filtering [4] has been used in the processing of the speckle data to overcome the 180° ambiguity in the relative orientation of the components of binary system [5]. IR speckle interferometry has also been used to measure the size and shape of dust shells surrounding either very young stars (possibly protostars) or evolved stars (cool giants and supergiants). The prospects for the discovery and study of proto-planets and protostars as well as for the understanding of the mechanism responsible for the mass loss of evolved giant stars appear to be excellent, especially with the new generation of giant telescopes now being planned.

Photon counting combined with high speed digital signal processing is now a standard technique in speckle experiments. However, the technique is still limited by the performance of available detectors and new detector systems are being developed. At Georgia State University an intensified CCD camera [6] is now used for a wide range of optical speckle interferometry programs. P. Nisenson, C. Papaliolios and R. Stachnik report that major hardware efforts at the Harvard-Smithsonian Center for Astrophysics include the development of computer-controlled CCD, intensified CCD and PAPA [7] photon counting speckle cameras. The PAPA (Precision Analog Photon Address) Detector is a 512x512 element sensor capable of generating accurate photon x-y (and t, if required) coordinates at megahertz rates. At Steward Observatory a real-time photoelectron event-detecting video system [8] has been developed based on an intensified Plumbicon camera and a Grinnell video digitizer. Improvements to the detector and data processing systems have been discussed by the Steward Observatory group [9].

Rotation shearing interferometry has been proposed as an alternative to speckle interferometry and has been successfully used to observe α Ori [10]. Beckers has described a new technique called differential speckle interferometry [11,12] which has been shown by R. Petrov, F. Roddier & C. Aime to yield a higher signal-to-noise ratio and higher angular resolution than conventional speckle interferometry. The importance of simultaneous observations at several wavelengths is now widely recognized and a method for obtaining objective prism spectra with diffraction limited resolution (speckle spectroscopy) has been described by Weigelt [13].

Image reconstruction from interferometric data has continued to be an area of considerable theoretical and practical activity. As a result the possibilities of phase retrieval from amplitude data alone are now better understood [1,14,15]. Phases have been successfully retrieved from speckle data using the Knox-Thompson algorithm [16] and the signal-to-noise ratio of the procedure has been discussed [17,18]. Phases have also been retrieved using the speckle masking algorithm [19] and B. Wirnitzer has shown that speckle masking has the same limiting magnitude as speckle interferometry. An image of α Ori has been reconstructed in the continuum using rotation shearing interferometry by C. &

F. Roddier and in Hα using differential speckle interferometry by J. Beckers & K. Hege. A well attended workshop on image reconstruction was held in Tucson in April 1983.

Speckle methods, especially roll deconvolution (G. Weigelt), and rotation shearing interferometry (F. Roddier & J. Breckenridge) are now being considered for improving the performance of large space telescopes. Adaptive optics are also under consideration as a means of improving the results of passive image reconstruction methods.

c) Visual Long Baseline Interferometry

The 11-m baseline prototype modern Michelson interferometer under development at the University of Sydney [1,20] was nearing completion in June 1984 with the installation of component parts essentially complete and final optical alignment in progress. The prototype features coelostats at each end of an 11-m baseline to direct starlight into the instrument, path compensation, active wavefront tilt correction, and rapid signal sampling to overcome the problem of phase fluctuations. This prototype is the first stage in the development of a major instrument with baselines up to ~1 km. A search for a suitable site and the design of the major instrument are under way.

The CERGA prototype long baseline interferometer (I2T) [21,22], which employs two 26-cm aperture telescopes, has been used with baselines in the range 6 to 40 m to measure the angular sizes of 10 stars with accuracies in the range 7 to 14% [23,24]. The more recent determination of diameters of equivalent uniform disks are based on the visual detection of very low contrast fringes for the largest possible baseline. These measurements are the first step in a program aimed at measuring the angular sizes of 50 stars of spectral types F-M with baselines up to 67 m. Labeyrie has continued his program to develop a large aperture synthesis array [22,25] and the second 1.5-m aperture telescope and central interferometer have been constructed. Alignment of a complete two aperture interferometer is in progress.

Shao reports that data have been obtained with the Mark II astrometric interferometer indicating that fringe visibility measurements are repeatable at the ±2% level and that ±0.5% is possible if corrections for seeing changes are made. Construction of the Mark III astrometric interferometer has commenced. This is a joint effort involving the Smithsonian Astrophysical Observatory, MIT, the U.S. Naval Research Laboratories and the U.S. Naval Observatory. The instrument will have three baselines: 20 m N-S, 15 m NE-SW, and 15 m NW-SE.

d) Infrared Long Baseline Interferometry

The CERGA I2T has been used as a Michelson type interferometer at 2.2 μm with baselines in the range 6 to 41 m to measure the angular sizes of giant stars [26] with accuracies in the range 2 to 14%. Future plans include extending the range of IR wavelengths from 1 to 5 μm with increased sensitivity at 2.2 μm.

An IR interferometer to be used in conjunction with the 1.5-m aperture telescopes at CERGA is being developed at the Observatoire de Lyon for use in the wavelength range 2 to 10 μm.

C. H. Townes reports that plans for a large two-telescope IR interferometer will come to fruition in 1984-1985. Based on preliminary work carried out with a 5.5-m baseline prototype, the instrument, now under construction, involves high-precision movable telescopes of 1.65-m aperture and will use heterodyne detection in the 10 μm atmospheric window. The instrument will be capable of both high angular resolution and precision astrometry.

The Multiple Mirror Telescope has been used in a number of observations and experiments designed to demonstrate its potential for high angular resolution research as an optical-IR interferometer and phased array [27,28].

The possibilities of long baseline interferometry with a coherent array of large ground-based telescopes have been discussed in a "Versatile Array" concept [29] and in connection with the ESO VLT Project [30,31]. D. Enard reports that the possibility of coherent coupling in the IR is to be a prime requirement in the development of the linear array concept for the VLT.

e) Interferometry From Space

The study of possible designs for high angular resolution interferometers for operation above the atmosphere has been pursued both in the U.S. and in Europe [32].

R. Stachnik reports on two interferometers being studied in the U.S. One is the Space Platform Interferometer (SPI) which is designed as a low cost, Explorer-class experiment which would put a Michelson spatial interferometer having a baseline of 2 to 50 m into space on board one of a number of space platforms under development. The second system is called the Spacecraft Array for Michelson Spatial Interferometry (SAMSI) and comprises two 1-m telescopes and a central station, for fringe measurement, allowing baselines up to 10 km to be scanned as the three spacecraft orbit the earth. SPI would provide a testbed for much of the technology required for more ambitious space interferometers and would operate from the UV to near-IR. A magnitude limit of 15 is predicted for 25 cm apertures. Fringe measurement, including phase determination, at a number of position angles would permit experiments in two dimensional aperture synthesis for some larger stars. SAMSI is estimated to have a limiting magnitude of 19 and it appears feasible to move the 1-m telescopes in spirals as large as 500 m in diameter to allow synthesis of very large two-dimensional apertures.

In Europe a group sponsored by ESA is also studying an array of three spacecraft which has been named TRIO [32]. TRIO shares many common features with SAMSI but differs primarily in its approach to the problem of propulsion. It is proposed to use solar sails and radiation pressure to rotate and position TRIO's spacecraft in order to avoid possible problems of vibrational noise associated with accessories such as gyroscopes and inertia wheels.

Cooperative studies between the U.S. and European groups are in progress. A workshop on "High Angular Resolution Optical Interferometry From Space," was held during the 164th AAS Meeting in June 1984 and a colloquium on "Kilometric Optical Arrays In Space," was to be held in October 1984 with support from ESA.

VII. PHOTO-ELECTRONIC IMAGE DEVICES

Report Prepared by B. Fort, W. Livingston, D. Monet, V. V. Prokof'eva, A. G. Scherbakov, G. Wlerick and B. Ye

a) Solid-State Arrays

CCD systems have proliferated to telescopes everywhere. Suddenly small telescopes have become much more powerful research tools producing results that formerly was obtainable only at the major installations. No doubt this topic will be expanded on at the forthcoming IAU Symposium No. 118.

At the Toulouse Observatory B. Fort and J. P. Picat have developed and applied a Cine-CCD camera for comet occulation and a new CCD camera for spectroscopy between 5000-11000Å. These cameras use the commercial Thomson

TX31133 buried-channel chip (576x384, 23-μm pixels, readout noise ~ 20 e r.m.s.). See Fort et al. [33]. Besides having reasonable photometric properties, the Thompson chip looms important for general use because it is readily available and has a history of low blemishes.

In the Soviet Union a new CCD array (A-1033) has been evaluated by Anoshkin et al. [34]. The A-1033 has a size of 1024x1024, 15-μm pixels, with a full well capacity of 10^6e. They report the readout noise is about 20 e at -196°C. Another array of 288x232 has been used by Abramenko, et al. [35] for stellar photometry.

A new CCD system utilizing the RCA 512x320 array has been used for the early detection of Halley's Comet by the PRC 1-m telescope at Yunnan Observatory.

D. Monet, at the U.S. Naval Observatory in Flagstaff, reports on the applicability of CCD images for the measurements of stellar trigonometric parallaxes. Monet and Dahn [36] find that such images are comparable to the best photographs measured on interferometric measuring machines (~ 5 milli-arcsec per exposure). Work continues to improve on this astrometric accuracy.

Experiences with the linear Reticon RL 1024B as installed at the Sayan Observatory magnetograph has been given by Markov [37, 38]. Likewise, Ye reports the RL 1024 is being tested on the Cass spectrograph of Yunnan's 1-m telescope.

K. Dowdney [39] has prepared an engineering evaluation of the Texas Instruments 800x800 3-phase CCD. This report is recommended for its thoroughness, describing in detail the equipment, procedures used, and the results. The device proved to have excellent linearity (.02% @ 8000e) low read noise (15e) and good vertical and horizontal charge transfer efficiency. An area of about 300 columns near the center of the chip is defect-free and the remaining irregularities should flat-field out very well. This is the CCD being distributed by the U.S. NSF Astronomy Grants Program.

The University of Arizona is constructing a unique CCD/transit instrument, for example, to detect supernovae by sampling 20 square degrees of sky per night to a magnitude limit of 22. A fixed 1.8-m primary feeds two RCA 512x320 CCDs operated in the time-delay and integration mode. That is, the CCD is locked out at the same rate that the image drifts across, so that residual flat-field errors are minimized [40].

A ripple of excitement ran through the instrument community with the announcement that Tektronix was planning to market a 2048x2048 CCD. According to the specifications the chip would have 32 μm square pixels, a full well capacity of 10^6e, a read-out noise of 2e, etc. It would be a thinned device with 2, 3, or 4 phase clocking. Whether or not this particular device materializes, it does signal the approaching obsolescence of our data handling techniques. To read out the n(10^6) element arrays of the future, and then to extract the desired information in a timely fashion will demand innovative methods. Simply scaling up our present techniques, i.e., ordering more mag tapes, will become totally inadequate.

b) Electronography

Lelievre et al. [41] continue to apply the large field electronographic camera to extra-galactic problems at the C.F.H. 3.6-m telescope. Details of the M87 jet have been uniquely recorded.

At the Vilnius Observatory (USSR) Drazdis et al. [42] have developed a Kron-type camera. They report that with a 35-cm aperture telescope a 14.5 mag object through a V filter gave images in 3 min.

P. P. Petrov [43] continues to apply the EIC-1 for spectroscopy at the Nasmith focus of the Crimean 2.6-m reflector. At a dispersion of 45A/mm, 4300-5400A, with a widening of 0.3 mm, 2 arc-sec seeing, 1 arc-sec slit (spectral res. ~ 2A), film R-type (fine grain, low sensitivity; DQE with EIC-1 about 5%), he records FG Sge B = 10.8 mag in 20 min.

c) Image Photon-Counting

C. Papaliolios has built a 2-D system which has been applied successfully for speckle imaging. The camera has a 512x512 pixel field which can operate at a photon detection rate as high as $2(10^5)\ s^{-1}$.

The PAPA (Precision Analog Photon Address) camera uses a high-gain image intensifier for photon detection. The position of a detected photon in the image plane is determined by a set of 19 photomultipliers, each looking at an image of the output face of the intensifier through a coded mask. The camera functions properly only if a single photon is detected. The rate at which this process can be repeated is determined primarily by the phosphor decay time of the intensifier, which is measured to be about 200 nsec for the P47 phosphor used.

Two photon counting spectrometers are operational on the Soviet 6-m reflector (Markelov *et al*. [44]; Belaga *et al*. [45]; Kopylov *et al*. [46]). In one case there is a 1000 pixel format having a dynamic range of 30-8000 photons per channel per hr. The second system employs two linear arrays of 500 pixels each; one for the object and one for the sky.

d) Television-Type Systems

Efforts continue at Alma-Ata and the Crimea to employ the image orthicon, isocon, and the antiisocon for photometry and astrometry. These programs are reviewed by Galinsky [47], Abramenko *et al*. [48], and Alexandrin *et al*.[49].

VIII. SOLAR/STELLAR SEISMOLOGY INSTRUMENTS
J. Harvey

Investigation of the interior structure and dynamics of the sun and other stars by observation and analysis of global oscillations is a rapidly developing area of astrophysics [50,51,52]. Large amplitude, pulsating variable stars have long been observed but exhibit only one or a few different modes of oscillation from which the average properties of the star can typically be determined [53]. The goal of the new research is to study stars which oscillate in a large number of different regions of the star's interior. Analysis of the different oscillations allows the interior properties of the star to be determined with resolution in the radial, and potentially the latitudinal, directions.

New instrumental and observational techniques are required because the photospheric amplitudes of the oscillation modes are small (e.g., for the sun, $\sim 10\ cm\ s^{-1}$ in velocity and $\sim 10^{-6}$ in intensity). Three types of measurements are currently made: Doppler shifts, intensity fluctuations and changes in the intensity profile near the solar limb. While general purpose telescopes have been used, a number of specialized telescopes have been developed and more are planned. Long time series observations are required to resolve the frequency structure of the oscillation modes. Observation interruptions caused by the day-night cycle have been overcome by using multiple instruments around the world, observing from the geographic south pole, and by observing from spacecraft.

Measurements of Doppler shift offer the best ratio of oscillation amplitude to background solar noise and are probably the preferred oscillation diagnostic in a wide range of stars. Accordingly, most instrumental effort is devoted to precise Doppler shift measurements. Since the oscillation amplitudes are of the order of cm s^{-1} and periods are > 100s, the emphasis is on stability and sensitivity. Measurements have been made with grating spectrographs using telluric or laboratory lines for reference [54,55]. With a resolved solar image, differential measurements are made by comparing Doppler shifts from different parts of the disk to overcome the intrinsic instability of existing grating spectrographs [56,57,58,59]. It is a frequent practice to employ more than one spectrum line to enhance the typically poor efficiency of grating spectrographs [55,60]. A number of interesting results have come from grating spectrograph observations but the difficulties of achieving two-dimensional imaging and intrinsic instability make these instruments nearly obsolete for solar work. Reflecting starlight from a stable Fabry-Perot etalon before it passes into a grating spectrograph has been proposed as a way of inserting reference absorption lines to enable precise Doppler shift measurements [61]. A ingenious technique that uses a large part of the spectrum of a star formed by a grating spectrograph which is then referenced to a laboratory stabilized laser has been proposed [62]. There is a plan to pursue this idea at the National Optical Astronomy Observatories.

Three other approaches have been used for precise Doppler measurements. Light is selectively scattered by hot alkaline metal vapors at wavelengths of the resonance spectrum lines. This principle has been used to obtain Doppler shift measurements with very good stability. The method is relatively inefficient and is restricted to solar observations with little or no angular resolution [63,64]. A variation of the idea, which depends on anomalous dispersion of light transmitted through the vapor, permits imaging and is also relatively efficient [65] A long series of solar observations with a transmission resonance device was obtained in 1984 at Mt. Wilson Observatory [66]. A similar spectrometer, designed to sense both of the sodium D lines, was used to measure apparent oscillations of α Cen A [67].

Another relatively old spectrometer is the Fabry-Perot etalon. The demands for etalon stability are great but one was recently successfully used for differential solar measurements [68].

A number of investigators have selected the Michelson interferometer operated at a nearly fixed path length difference as the basis for precise Doppler shift measurements [69,70,71]. It is possible to achieve good stability with a temperature-compensated design employing selected glasses [72]. An absolute wavelength reference can be provided by a laboratory light source such as a stabilized laser. The devices are efficient and compact. Both solar and stellar observations have been attempted.

Other Doppler-sensitive spectrometers have been tried such as Lyot filters and heterodyne systems but most current activity is centered on grating spectrographs for stellar observations, resonance scattering and transmission devices and specialized Michelson interferometers for solar and stellar work.

The relative merits of measuring oscillations by Doppler shift compared with intensity have been discussed [73,74]. Considering available equipment, intensity measurements offer advantages for all but the brightest stars and most solar observations. Measurements of the total solar irradiance from the Solar Maximum Mission satellite greatly improved our knowledge of solar oscillations [75]. Three-color measurements of solar oscillations were obtained from a balloon in the stratosphere [76]. Solar oscillations were apparently detected with what must be the smallest aperture telescope ever built, 10 µm [77,78]. Additional intensity measurements of the sun, now with some angular resolution, were made at the Crimean Astrophysical Observatory in 1983 using a 16x16 integral detector array [79]. Some spectral features show an order of magnitude larger intensity fluctuations than the continuum. Thus the CN band at 3883 Å and the

CaII H and K lines have been used to observe solar oscillations with angular resolution [80,81,82].

The prospects of directly observing weak intensity oscillations of stars from the ground are not encouraging because of noise from scintillation and extinction fluctuations [83,84,85]. An attempt to detect solar-like oscillations on other stars using conventional photometry was not successful [86]. Proposals for reducing the effects of atmospheric noise by using reference stars and different wavelengths of the star have been advanced [87,88]. This second idea has already been used to detect apparent oscillations of ε Eri [89] and is the basis of instruments under development by the Center for Astrophysics [90] and the National Optical Astronomy Observatories.

Measurements of changes in the limb darkening function of the sun caused by global oscillations have been undertaken by three groups. The SCLERA group in Tucson have added several detectors to their system to enable many limb positions to be measured simultaneously [91]. A group from the Sacramento Peak Observatory, observing from the south pole measured the entire solar limb and obtained several remarkably long unbroken observation sequences [92,93]. A group observing at the Pic du Midi continue to develop their limb instrument [94,95].

In the near future, the problem of obtaining long, unbroken time sequences of oscillation observations is being addressed by solar and stellar observations from the south pole [96] and by networks of instruments deployed at different longitudes at low latitude. Two networks for observing solar oscillations with little or no angular resolution are under development [97,98]. Both networks will employ resonance scattering spectrometers. Another network, with good angular resolution, has been proposed by the National Optical Astronomy Observatories [99]. A more modest, two-station approach is under development by the California Institute of Technology [100].

Space is an obvious place to achieve continuous observing and also freedom from noise caused by the earth's atmosphere. A number of proposals have been made for both solar and stellar oscillation observations from space. A joint French-Soviet experiment has been proposed to observe solar oscillations with low angular resolution during the cruise phase of the Soviet Phobos mission to Mars [100]. The Solar and Heliospheric Observatory proposed to the European Space Agency includes both imaging and non-imaging solar oscillation experiments [102]. A working group recently completed a study of the advantages of solar oscillation observations from space for the National Aeronautics and Space Administration [103]. Stellar obscillation observations from space have been discussed by several authors [104,105,106,107]. Probably the most widely-discussed proposal is the Probing Stellar Interiors via Variability and Activity (PSIVA) project which was a response to ESA's interest in new mission concepts [108].

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Note: Leningrad ≡ "New Techniques in Astronomy," Leningrad, Nauka, 1984.

Meudon ≡ "Proceedings of the Workshop on Space Research Prospects in Stellar Activity and Variability," (eds. A. Mangeney and F. Praderie) Observatoire de Paris-Meudon, 1984.

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