DIVISION IX - OPTICAL TECHNIQUES

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COMMISSION 9: INSTRUMENTS AND TECHNIQUES

Report 1993–1996

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1. Introduction

During the period covered by this report, major progresses have been achieved in various fields of astronomical techniques and instruments. The era of large telescopes has been opened with the commissioning of the 2 Keck telescopes and the final construction phase for major facilities (ESO, JNLT, LBT, Gemini, etc) . More than ten telescopes, with aperture larger than 8m, will be ready to scrutinize the sky, at the beginning of the next century. A spanish project (GRANTECAN) remains incompletely financed at this time. The power of these telescopes will be maximum when full diffraction limit capabilities will be available at their focus. The period 1994-1997 has seen major and spectacular achievements with realisation of several operationnal adaptative optic systems on 4m-class telescopes (ESO, CFHT) . Diffraction limits have been reached at near-IR wavelength and partial correction, even in the visible, are bringing resolution comparable to space observations. All 8-10m projects require adaptative optics and have plans for it. In the meantime, 3-4m class telescopes are beeing equiped as well,so that AO will appear everywhere within the next 3 years. The necessary complement of adaptive optics, ie: the laser guide star, is thoroughly studied in order to provide full coverage for atmospheric compensation all over the sky. Projects of monochromatic and polychromatic laser stars are flourishing in relation with all telescopes with aperture of 3m-plus adaptative optics projects. Field coverage and achievable resolution require good pixel sampling and therefore large format detectors. Projects of very large format cameras for the visible and infrared are considered, up to 16kx16k (MEGACAM at CFHT for 1.5 degrees field). Progress has been obtained in the industry to reduce gaps in between bootable CCDs, to reduce amplifiers noise and improve sensitivity. High angular resolution capabilities will gain another magnitude when the actual developments on interferometry with small telescopes will be tranfered to arrays of large telescopes (ESO, Keck, etc) . Resolutions of 0.001 arc. sec will be available within 5 years leading to a gain of a factor 1000 compared to a 3.5m telescope operating today without adaptive optics.

2. Telescopes – Instrumentation

2.1. TELESCOPES COMMISSIONED OR UNDER CONSTRUCTION

Detailed information for most of the large telescopes can be found in the proceedings of the SPIE conference on Optical Telescopes of Today and Tomorrow, held in Landskrona (Sweden) in may 1996. Most consortia do also publish regular newsletters. A brief resume is given here.

I. Appenzeller (ed.), Reports on Astronomy, Vol. XXIIIA, 499–514.

2.1.1. *Keck telescopes*

After its completion in 1993, the Keck I 10m telescope has now come into routine operation, with image quality lower than 0"5. First class scientific results have been obtained with the first instrumentation, the High Resolution Echelle Spectrograph (HIRES) and the Near Infrared Camera (NIRC), soon followed by the Low Resolution Imaging Spectrograph (LRIS) and the Long Wavelength Spectrograph (LWS).
The Keck II telescope, virtually identical to Keck I, started operations in October 1996. At the same time, NASA became a partner in the project, with the specific aim to discover solar systems beyond our own.An adaptative optics system is to be installed on Keck II for 1998, followed by a similar system on Keck I and the coupling of the two telescopes for interferometry.
See also http://www2.keck.hawaii.edu

2.1.2. *Eso VLT*

The construction of the four 8m telescopes is progressing according schedule, as well as the development of the Paranal site in Chile. A smooth development is further ensured by the ratification late 1996 by the Chilean Senate of the Agreement with Eso.The fourth 8.2m mirror blank has been completed by Schott in Germany, while the polishing of the third is under way at Reosc in France. First light of the first telescope unit is still foreseen for the end of 1997. The first serie of instruments is under construction, comprising a Near IR Camera (CONICA) with adaptive optics (NAOS), a slit multi-object spectrograph (FORS) with two units, a near IR imaging spectrograph (ISAAC), a high resolution UV echelle spectrograph (UVES), a fiber multi-object spectrograph with Argus mode (FUEGOS) and a thermal IR spectro-imager (VISIR). The second generation instrumentation plan has been discussed, and the first of those instruments, a visible and near IR imager and multi-object spectrograph (VIRMOS), has received the kick-off in late 1996.
The interferometric mode of the VLT has received special attention, with a new start in 1996, including the construction of three auxiliary telescopes of 1.80 m diameter and the first IR instrumentation.
See also http://www.eso.org

2.1.3. *Gemini*

The Gemini project is an international venture set-up to construct two 8m telescopes, one on Mauna Kea, Hawaii, and one on Cerro Pachon in Chile.Both telescopes are designed to deliver 0.1 arcsec images at 2.2 microns and will be optimised for IR observations, specially in Hawaii.The telescopes will be operated with an f/16 IR Cassegrain focus, where focal plane emissivities are expected to be close to 2% only, and a f/19.6 optical Cassegrain focus. The initial instrumentation plan comprises a near-IR imager, a near-IR spectrograph and a multi-object spectrograph for the northern unit.For the southern unit, a multi-object spectrograph and a High Resolution optical spectrograph are foreseen, in addition to a mid-infrared imager shared between both telescopes.A mid-IR echelle spectrograph will also be shared between UKIRT and the northern Gemini unit.All major contracts in facility instrumentation have been placed. At the time of writing, the initial grinding of the No.1 blank is complete, polishing and figuring are expected to be completed by late 1997 at Reosc (France).Blank No.2 has been produced by Corning and the back (convex) surface successfully generated. Foundation work is complete at both sites, and erection of the steel structures was progressing well by the end of 1996. Preassembly of the first telescope structure had started also in Le Creusot (France) by late 1996. First light for the northern unit is foreseen in December, 1998, while the southern one is planned to see first light in September, 2000.
See also http://www.gemini.edu

2.1.4. *JNLT*

The Japanese National Large Telescope, now named "Subaru" (the Pleiades), is a 8.2m telescope with a thin-meniscus type primary mirror, to be placed at Mauna Kea, Hawaii. Since the effective start in 1992, the erection of the structure and building has been progressing well, and despite a tragic fire in the upper enclosure in january 1996, which caused a delay of a few monthes, the construction is near completion.Special care has been taken in the design of the enclosure to minimise image-degradation and ensure rapid thermal equilibrium.

The 8.3m blank has been successfully completed by Corning Glass, and is now in the polishing phase by Contraves, for delivery in 1997. A large and versatile instrumentation program is foreseen for this single telescope, including four Cassegrain instruments (Faint Object Camera and Spectrograph, Infrared Camera and Spectrograph, Cooled Mid IR Camera and Spectrograph, and a Coronographic Imager with Adaptive Optics), two Nasmyth ones (High Dispersion Spectrograph and OH Suppressor Spectrograph) and a Wide-Field Prime Focus camera.In addition, three base-line development programs are well under way for immediate use with the telescope:thinned CCD's, a Cassegrain Adaptive Optics system, and a Mid-Infrared test observing system.
First light is foreseen in 1998, for a full operation in 1999.
For more information,see http://chain.mtk.nao.ac.jp

2.1.5. *LBT*

The Large Binocular Telescope (former Columbus) project consists of two 8.4m mirrors in a common mount.The telescope is to be installed on Mount Graham in Arizona.Legal battles about the precise location of the telescope seem to have come to an end in late 1996 and the consortium has been further encouraged by incoming of new partners.The project can therefore fully go ahead. The casting of the first of the two fast (f/1.14) primary mirrors (borosilicate honeycomb mirrors) should be completed at University of Arizona when this paper comes out.Focal stations will be developped at the two (trapped) Cassegrain fast (f/4) optical foci, at the two Gregorian (f/15) IR foci, and at the phase-combined common center.First instrumentation should comprise an Optical Direct Imager, a Faint Object Spectrograph, a Near IR Camera and a Medium resolution IR spectrograph.Special emphasis will be put on interferometry which is a specific goal of this particular design.
See also http://www.as.arizona.edu

2.1.6. *Magellan*

The Magellan project intends to install two 6.5m optical telescopes in the southern hemisphere at Las Campanas Observatory in Chile.Foundation work for both telecopes and the auxiliary building is complete.The borosilicate primary mirror for Unit 1 has been cast at U.of Arizona and is in the queue for polishing.The mount for Unit 1 is currently assembled. Addition of new partners in 1996 has enabled the project to proceed with telescope No. 2.
See also http://www.ociw.edu

2.1.7. *MMT*

The Multi Mirror Telescope is operated since 1979 on Mt.Hopkins in Arizona with its six 1.8m mirror array in a single mount.Following the progress made at Steward Observatory in casting large and fast borosilicate honeycomb mirrors, it has been decided to replace the array by a single, 6.5m primary mirror, to more than double the collecting power and at the same time increase susbtantially the field of view.
The f/1.25 primary has been cast and is currently polished.Five different Cassegrain optical configurations are foreseen, to make best use of both existing instruments and new facilities.Those include an optical fiber-fed spectrograph with 300 optical fibers, and a large CCD imager with field 22'x22'. The existing building has been modified and the major steel telescope structures fabricated.First light for the f/9 focus is expected in early 1998.
See also http://www.as.arizona.edu

2.1.8. *Galileo*

The italian national telescope GALILEO (TNG) is an active optics telescope with primary mirror of 3.58m, f/11 R–C configuration and two Nasmyth foci, erected on the Roque de los Muchachos (La Palma, Spain). Its official dedication took place on June 29, 1996, presided by the King of Spain Juan Carlos I. Major activities in 1996 included the transportation of the mirrors from Zeiss in Germany to the site and their aluminisation inside the WHT tank, the successful test of the novel rotation device of the dome (made by THK Japan), and the final acceptance of the optics for the Rotator/ adapter units

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from Officine Galileo.
All parts of telescope and dome have been put together, and now are near completion. First light is expected before the end of 1996. At the same time the first scientific instruments (CCD and near-IR cameras, with adaptive optics modules in front of both of them, and a low resolution spectrograph) are nearing completion. The detailed design of a high resolution spectrograph is under way, possibily to be shared with other partners on the site.
See also http://www.pd.astro.it/TNG/TNG.html

2.1.9. *HET*

The Hobby*Eberly Telescope (HET) is a special purpose telescope optimized for spectroscopy, scheduled for completion, commissioning, and initial scientific operation during 1997 at McDonald Observatory. HET is a 9-meter class Arecibo-style optical telescope with a primary consisting of 91 one-meter hexagonal Zerodur segments of spherical figure which combine to form an 11 meter by 10 meter hexagon. HET points at a fixed zenith angle of 35 degrees and achieves sky coverage from −11 to +71 degrees declination by rotating the telescope in azimuth between observations, providing 70% coverage of the sky observable from McDonald. Tracking is achieved by moving the upper secondary-mirror unit of the telescope, instead of the whole telescope. The spectroscopic instruments will be fiber-fed and located in a temperature-controlled room.Most of the osbervations will be done by queue scheduling. Construction of the primary is well under way, and first light is foreseen in 1997.
See also http://www.as.utexas.edu

2.1.10. *Themis*

Themis is a 90cm Ritchey-Chretien telescope, under vacuum, for solar studies, constructed in collaboration between France and Italy.It has been installed in Tenerife island, in the observatory del Teide, where other solar and astornomical instruments are already operating and officially inaugurated on June 29, 1996.
An adaptive optics system compensates for atmospheric turbulence.The present instrumentation is specially designed for simultaneous studies of many spectral lines, with high angular, spectral and temporal resolution.It includes a prime focus polarisation analyser, a complex of two spectrographs used in serie (one predisperser, and one echelle ananlyser, with 20 CCD cameras), and one bi-refringent filter with Fabry–Perot analyser.
A dedicated database (BASS 2000) has been set-up in the south of France (Bagneres de Bigorre)to collect data from Themis, as well as from other french solar observatories, and is connected to the database from the SOHO satellite.

2.2. INSTRUMENTATION IN OBSERVATORIES

2.2.1. *Universities of California (report by T.Misch)*

The Automated Multi-Object Spectrograph (AMOS) is in the final stages of commissioning at the prime focus of the Shane 3-m telescope. AMOS uses approximately 60 fibers (100 are expected in the near future), robotically positioned across a one-degree field. The fibers feed either the red (450–900 nm) or blue (350–550 nm) channel of a stationary spectrograph equipped with two 2048x2048 CCDs. Fiber positioning time is typically less than five-minutes per field. Further information can be found at the following WWW sites: http://astro1.nevis.columbia.edu and http://www.ucolick.org/~sla/mos/index.html.
UCLA has constructed a two-channel infrared camera system (for the 1–5 microns regions) which is used regularly on the 3-m telescope. Two wavelengths bands, separated by dichroic beam-splitters, can be observed simultaneously. The short-wave channel uses a 256x256 HgCdTe NICMOS 3 chip and the long-wave channel has a 256x256 InSb SBRC detector. Each channel is a general purpose camera with broad and narrow band filters and has a spectroscopic capability with R=500. A polarimeter module with an achromatic halfwave plate for 1–2.5 microns can be installed automatically. More details and numerous scientific results are described on the Home Page of the UCLA Infrared Imaging Detector Lab; http://www.astro.ucla.edu/irlab/irhome.html

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The Katzman Automatic Imaging Telescope (KAIT) is a 0.76-m Ritchey-Chretien reflector at Lick Observatory, which has been commissioned in 1996 following successful operation of a prototype at Leuschner Observatory. It is operated by a team led by Professor Alex Filippenko (U. of California, Berkeley). It performs broad-band optical imaging with a thermoelectrically cooled CCD in unattended, fully robotic mode. The telescope is used almost exclusively for an automatic supernova search, and for long-term monitoring programs. see also Richmond, Treffers, and Filippenko (1993, PASP, 105, 1164).

The Hamilton High Resolution Echelle Spectrometer, designed by Dr. S. Vogt (U. of California, Santa Cruz), and commissioned at the coude focus of the Shane 3-m telescope in 1986, has been upgraded by Vogt in late 1994. The upgrade consists of an improved Schmidt corrector and field flattener, resulting in a 2.5-fold increase in limiting resolving power. The instrumental profile (with slit width at 0.2 arcseconds) is now less than 0.006 nm fwhm at 600 nm, for a resolution of greater than 100, 000. With a typical observing slit of 1.2 arcseconds, the resolution is about 60, 000. Large format CCDs (2048x2048 15-micron pixels) now make it possible to record wavelengths from about 350–950 nm in a single observation.

The Visible and Infrared Imaging System (VIRIS) is an addition to the Lick Infrared Camera (LIRC-2) that permits imaging in the visible (350–1000 nm) and near infrared (0.9–2.5 microns) with a single instrument, mounted at the cassegrain focus of the Nickel 1-m telescope. Visible imaging is achieved with a 2048x2048 CCD while the near infrared is detected with a 256x256 NICMOS array. The telescope beam is easily switched between the two detectors, or can be sent to both, simultaneiously, with a dichroic beamsplitter. VIRIS was designed by Drs. James Graham and Lynne Hillenbrand (U. of California Berkeley) and Tony Misch (U. of California, Lick Observatory). The instrument was commissioned in summer, 1996.

A new prime focus CCD camera will be commissioned for the 3-m Shane Telescope in early 1997. The camera consists of a five position filter wheel, a double-slide shutter, a guide camera on a translation slide, and a 2048 x 2048 SITe thinned, backside illuminated CCD in a liquid-nitrogen cooled dewar. All components are fully remotely operated. The camera operates behind a filter corrector and atmospheric dispersion compensator (ADC). Sampling is 0.29 arcseconds per pixel for a total field of 9.8 arcmin on a side. Principal Investigators are Michael Bolte and Richard Stover (U. of California Santa Cruz, Lick Observaotry). Project engineer is Mathew Radovan.

The Aerospace Near-Infrared Camera incorporates a 256 x 256 NICMOS 3 HgCdTe detector array housed in a compact side-looking dewar. The filter wheel, together with the detector array, are fixed to a plate and cooled by a thermal switch attached to the liquid nitrogen vessel. Modular optical benches which carry their own field apertures and reimaging optics and are interchangeable are mounted to this plate to provide for different plate scales and fields of view. The optics are optimized for use with the f/17 Shane 3 meter telescope of Lick Observatory. A coronagraphic mode is also available. Various read-out rates are available including a "speckle" mode with integration times as short as 0.1 seconds. The instrument was designed and constructed at the Aerospace Corporation by Rick Rudy, Yaniv Dotan, Donald Roux, David Warren, and Robert Young. Project Co-Investigators are Rick Peuter (U. of California San Diego), Rick Rudy (Aerospace Corporation), and Andrea Ghez (U.of California Los Angeles).

The Aerospace near-IR spectrograph is a long-slit instrument which incorporates NICMOS 3 arrays. A common field lens feeds a beam-splitter which separates the light into two distinct channels: a "blue" channel which covers 0.8–1.4 microns, and a "red" which ranges from 1.4 to 2.5 microns. Each channel contains its own collimator, grating, camera, and array. To provide full wavelength coverage over the 2.4 cm of useful spectral range present in each channel, the 1 cm arrays are translated in the spectral dimension. This also provides for oversampling the data. The long-slit affords 110 arcseconds coverage in the spatial direction. Resolution ranges from approximately 600 at the short-wave end of each channel to 1000 at the long-wave extreme. The spectrograph mounts to the same platform which supports the camera, either of which can be selected by a mirror which pivots to redirect the telescope beam. A CCD camera provides for direct slit guiding. The instrument was designed and contructed at the Aerospace Corporation by Rick Rudy, Yaniv Dotan, Donald Roux, David Warren, and Robert Young. Project Co-I's are Rick Peuter (U. of California San Diego), Rick Rudy (Aerospace Corporation), and Andrea Ghez (U. of California Los Angeles).

The Infrared Astronomy Group at UC Irvine is currently building a portable, mid-infrared (8 – 28 micron) imaging Fabry–Perot interferometer (MIRFI) for use with a variety of different infrared telescopes, including the Shane 3-m , IRTF. UKIRT, and Keck I and II telescopes. The instrument will provide

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diffraction-limited (~ 0.1 arcsec/pixel) imaging at extremely high spectral resolution (R ~ 10^5). The two major components of MIRFI consist of (1) a pair of carefully matched cryogenic Fabry-Perot interferometers and (2) a large 256x256 mid-infrared detector array. Principal investigator is Dr. R. P. Garden (U. of California Irvine), project manager is John Gandolfo. More information about MIRFI can be found at: http://ir3.ps.uci.edu.

2.2.2. *Mc Donald Observatory (provided by P.Kelton)*

The main technical achievement at McDonald since 1994 has been the construction of the Hobby*Eberly Telescope (HET)(see telescope section).
On the other hand, the McDonald 0.76m telescope was recently transformed into a dedicated imaging facility with the addition of an f/3.0 Prime Focus Corrector (PFC) and 2048x2048 CCD system. The system was designed and built by C. Claver and P. MacQueen. The PFC provides a 1.10 square degree field, with the current CCD covering 46.2x46.2 arcminutes. The PFC has demonstrated excellent performance and has become a heavily used research tool at McDonald.

2.2.3. *Special Astrophysical Observatory (from I.Kostiuk)*

1. A new universal spectrograph MAUSER (Multi Aperture Universal Spectrograph for Extragalactic Research) equipped with a tip-tilt guiding system is being developed for the 6-meter telescope of SAO. It is to operate in 4 modes : direct imaging, long slit spectroscopy, multi pupil spectroscopy, and multi object spectroscopy with a mask.
It is supposed to achieve DQE of 40% at 5000 A when used with the Russian CCD 1K x 1K (read out noise of $5e^-$).

2. In 1995–1996, a project on SAO's next generation CCD-controller for big arrays/mosaic detectors, with a modular architecture, 16- and 32- bit digital signal processors (ADSP-2181 and ADSP 21060), is being realized.
The basic aim of the project is the achievement of extreme sensitivity and photometric precision by means of digital CDS-processors, the provision of high stability when converting charge to a digit code and the insertion of electric calibration of the video signal processing channel.
Detailed studies of signal amplitude distortions (non stabilities and non linearities) , noise characteristics and methods of minimizing the read-out noise have been carried out. On the basis of this study, the architecture of CCD-controller has been defined and electronic modules have been developed. In 1996, the production of the first 10 specimens of controllers is foreseen.

2.2.4. *Max Planck Institutes*

Speckle Imaging. As a successor to the speckle camera, SHARP I, the development of a new instrument based on a 1024 square HgCdTe Rockwell detector array is planned. The new camera has a much larger field of view than SHARP I with identical spatial resolution, and a factor of 6 improvement in read-out noise. Short time exposures (not limited by photon noise) will show a large improvement in sensitivity. The camera is planned to be used at the ESO 3.5 m NTT.Inclusion of a tip-tilt correction system would allow to obtain also high angular resolution in long exposure images.

High resolution imaging. SHARP 2 is a new camera for diffraction limited imaging between 1 and 2.5 mu, provided for the general user at the ESO 3.6 m telescope. Its first successful observing run was at the end of October 1995, together with the adaptive optics system ADONIS. The camera uses a NICMOS III array. The dewar housing incorporates a wheel with three interchange able objectives, allowing diffraction limited imaging over the entire detector wavelength range with image scales of 35, 50 and 100 milli-arc seconds per detector element. Two additional filter wheels in the dewar carry narrow band filters , as well as standard photometric filters and a tunable interference filter. Two Fabry Perot etalons (resolution of 1000 and 2500 respectively), as well as a polarizer can be inserted in the optical path in front of the camera. The commisssioning run observations have demonstrated that the camera fulfills its photometric specifications.

Near infrared integral field spectroscopy. Due to the uniqueness of its image-slicing technique (Weitzel et al. 1996) and the resulting technical leap in near infrared observations, the MPE imaging spectrometer 3D has attracted increasing attention. The instrument has been developed further, with addition of a grism slide allowing immediate interchanges between two grisms. A wide range of grisms covering the H and K bands at spectral resolutions of 1000 and 2000 are now available. High spectral coverage is achieved by sub-stepping the spectrum on the detector via use of a cold piezo driven mirror within the cryostat. A variety of interface modules allow the instrument to be coupled to various telescopes.
Two versions of a tip-tilt corrector ROGUE have also been commissioned for use in conjunction with 3D, to provide partial seeing correction and quick changes in image scale.
The last two observing runs at the 4.2 m WHT on La Palma, and the ESO/MPIA 2.2 m telescope on La Silla have been very successful. In parallel, the successor instrument to 3D, SPIFFI, is being developped. It is built around a 1024 square HgCdTe array to obtain a four times larger field of view and spectral resolution. The optical design is nearly complete and the first test pieces for the image slicer are being fabricated. Simultaneously, a new instrument , SINFONI, is being proposed for the ESO VLT. This instrument will combine the capabilities of SPIFFI with a curvature sensor based adaptive optics system for high angular resolution integral field spectroscopy of faint objects.

Detector development. Within the framework of ESA's pre-development projects for FIRST, work has progressed on far infrared array detectors. Out of a number of possible candidate materials for the wavelength range beyond 120 mu m, stressed Ge:Ga and n-doped Ga:As have been selected.
The program for s-Ge:Ga is already under way (FIRSA)and its system level design is done at MPE as sub-contractor of the Belgian microelectronics company IMEC. Both two year programs aim at building and testing a 16x16 element model array with integrated cryogenic read out electronics that can be used up to 220 mu. There is hope to extend the wavelength range up to about 300 mu by using Ga:As array detectors. Work on this type of detector, started two years ago. In cooperation with other international institutes, the production of multi-layer structures of differently doped Ga:As was accomplished. The first of these detectors is currently being tested. The project FIRSA is sponsored by ESTEC.

2.2.5. *Crimean Astrophysical Observatory (from R.E.Gershberg)*

Theorical work for the design of Echelle spectrometers with concave diffraction gratings as secondary dispersing element has been performed. It is shown that an echelle spectrometer for a given wavelength interval, detector area, and volume limitations, and the minimum spacing of orders has 2 degrees of freedom ; a spectrometer that provides for the highest spectral resolving power and fits the same limitations has 1 degree of freedom ; and an autocollimation layout of a spectrometer with the highest resolution is completely determined for a given entrance slit and required spectral resolving power. Versions for spherical and toroidal gratings that operate in both minimized and non-minimized astigmatism modes are considered.
The instrument at the base of the Magneto-Optical Filter, to study active regions in sodium spectral lines using both Dopplergrams and magnetograms has been commissioned with a 512x512 Panasonic video camera.It was made and supplied to Crimean Astrophysical Observatory (CrAO) by University of Southern California.The instrument has been installed at the Solar Tower of CrAO. It is one of two similar instruments devoted to high-1 degree helioseismology "Mount Wilson-CrAO" network.

2.2.6. *Observatoire de Haute-Provence (OHP, France)*

A new spectrograph has been put in operation in 1994 at the Cassegrain focus of the 1, 93 m telescope of Observatoire de Haute Provence (France). This instrument, named Elodie, is a fibre-fed echelle spectrograph, designed mainly for high resolution spectroscopy. A cross-correlation method is used to perform very accurate radial velocity measurements, needed in asteroseismology and in the seearch, by the Doppler shift method, of brown-dwarfs or giant planets orbiting around nearby stars. Elodie has been designed as an updated version of the cross-correlation spectrometer Coravel used since 1977 at OHP and at ESO.

The major gains with respect to Coravel were achieved by using numerical correlation, a low read-out noise CCD, optical fibers to feed the spectrograph and by installing Elodie in a fixed position within an isothermal cell. A general description of the instrument together with the data reduction algorithms are presented in Baranne et al (1996, A&A Suppl., 119, 1). A spectrum ranging from 3906 to 6811 A is recorded at resolution R=42000 in a single exposure on a1024x1024 CCD. An automatic on-line data reduction is available, which reduces the echelle spectra and computes cross-correlation functions. The instrument allows the measurement of radial velocities with an accuracy of about 13 m/s, for stars up to 9th magnitude in less than 30 minutes exposures.
This has resulted in the outstanding discovery of the first extrasolar planet orbiting a solar type star, 51 Pegasi(M. Mayor and D. Queloz 1995, Nature 378, 355).
See also http://www.obs-hp.fr

2.2.7. *UKIRT*

The 58x62 InSb arrays in both of UKIRT's main 1–5 mu instruments, the IRCAM3 camera and the CGS4 spectrometer , were replaced by InSb 256x256 arrays.
A 7–25 mu imager/spectrometer for shared use at UKIRT and Gemini North is under construction at the Royal Observatory Edinburgh with delivery expected in 1998. Construction was started in late 1996 at Oxford University on a "fast track" 1024 sq camera covering 1–2 mu for UKIRT ; delivery is expected in late 1997 or early 1998. Design work on a 1024 sq 1–5 mu advanced imager/spectrometer is under way, with delivery expected near the year 2000. The UKIRT Upgrades Programme, a comprehensive project involving the introduction of a fast tip/tilt/focus secondary mirror, primary mirror cooling, active primary mirror support, dome ventilation, and dome insulation, and with a goal of achieving near diffraction-limited image quality by end 1997, has made impressive progress since 1994. By end 1996, all major modifications and installations were expected to be completed.

2.2.8. *CFHT*

The most important achievement at CFHT was the commissionning of the Adaptive Optics Bonnette (AOB) in 1996 (see Adapative Optics section). Laboratory tests were succesfully passed for the OASIS spectrograph (integral field spectrograph with various options), specially designed for the AOB, preparing its commissionning in the first semester 1997. In addition, CFHT is preparing a future instrumentation program dedicated to wide field imaging with good image quality (0.3"). An 8k by 12k CCD camera is under construction with the cooperation of University of Hawaii. This camera will prepare the realisation of a 16k by 16k CCD camera built by a consortium of laboratories in France, with the objective to cover at least 1 square degree at the prime focus. Three near-infrared cameras, up to 2k by 2k, are under construction to equip the AOB, direct imaging camera and spectrographs.
See http://www.cfht.hawaii.edu for more details.

2.2.9. *Astronomical Institutes in China*

1996 has seen the decision to build a Large Area Multi-Object Fibre Spectroscopic Telescope (LAMOST). This is a special reflecting Schmidt telescope, with 4m aperture, f/5 focal ratio and a 5 degrees field of view. It has a fixed, optical axis, and objects can be observed during 2.5 hours. The observable sky region goes from 10 to 90 degrees in declination. The tracking process and the shape of the Schmidt plate have to be changed for different declinations.This is done by active optics. About 4000 optical fibres are foreseen in the focal surface and will lead to about twenty spectrographs. LAMOST is expected to be completed in seven years. Various engineering studies and designs are going on.
A new 1.05 m telescope was completed, with one R-C focus with excellent image quality and a prime focus.
An echelle spectrograph was finished and installed at the coud focus of China's 2.16 m telescope. There are two echelles in this spectrograph. The linear dispersion goes from 17.6 A/mm to 0.4 A/mm.
An experimental system for stellar interferometry is being developed. Substantial results have already been obtained. After a thin-mirror active optics experimental system was finished in 1993, a segmented-mirror active optics system is being developed since 1994. A Shack-Hartmann device for telescope real

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time telescope testing is also been realised.
A solar space telescope project is being considered in China. The main optical telescope would have a 1 m aperture, and would be equiped with a 2-D real time spectrograph, with a 16-channel universal birefringent filter.
At the end of 1994, a 3 mm receiver (cooled Shottky) was developed for the 13.7m millimeter radiotelescope. A new 3 mm SIS receiver has now been prepared , with a receiver noise temperature in the 85–115 GHz band of 40K or less, which will replace the former receiver in the near future.

2.2.10. *Mount Wilson Observatory*

Mount Wilson Institute manages the Mount Wilson Observatory under an operating agreement with the Carnegie Institute of Washington. Two major telescopes are available for guest-observer use : the 60-inch and 100-inch reflectors, both with a Newtonian (f/5), a bent Cassegrain (f/16) and a coud (f/30).focus. Both telescopes have delivered diffraction-limited images in the visible with adaptive optics systems. The adaptive optics system for the 60-inch telescope has however been decommissioned.
Limited instrumentation is available for guest observer use. The HK spectrophotometer records the fluxes in the Ca 11 H and K lines relative to the nearby photospheric continuum. It can be used on either the 60-inch or 100-inch telescope. A cooled CCD camera, with a CBAF-Cassini-type chip (1024x1024 pixels) is available for use at the 100-inch telescope. The coud spectrograph of the 100-inch is currently not in use. Guest observers are invited to use the 60-inch and 100-inch telescopes in exchange of a nightly charge equal to the cost of operations.
Don Walters of the Naval Postgraduate School at Monterey, who has been monitoring seeing at North American sites and Hawaii for a number of years, reports that the seeing on Mount Wilson is superior to any other observatory in North America, and is as good as the seeing in Hawaii. The exceptional seeing on Mount Wilson makes it a valuable tested and research site for adaptive optics and interferometry.It is one of the principal reasons for its selection as the site for the CHARA interferometer (see section 2.4).
The Observatory has made available for educational use a research-quality 24-inch telescope obtained on long-term loan from CalTech, which has been automated so that the telescope and CCD camera can be operated by computer and modem from anywhere in the world. The 24-inch facility is now in use by schools in 31 states plus Japan and Australia. Time on the 24-inch telescope is also available to the amateur community at a charge covering cost of operations.

2.3. ACTIVE AND ADAPTIVE OPTICS

A recent meeting in Maui (8-12 july 1996), gives an extensive update on Adaptive optics (AO) and related topics. Outstanding results are now almost routinely obtained with existing adaptive optics systems operating at ESO, CFHT and University of Hawaii. Others systems are being installed on several 3-5m telescopes such as Mt Palomar, Mt Wilson, Lick observatory, ARC, Calar Alto, and will soon become operational. Most of the 3m class telescopes will be equiped with adaptive optics. Industrial companies are also involved in production of such system in USA, France, etc. Two types of wavefront sensors (WFS) are being considered (Shack-Hartman and curvature sensor) to feed deformable mirrors produced by industrial companies. CCDs and Avalanche diodes are used as WFS detectors.

These prototypes serve as test benches for further developments of adaptive optics systems to be installed on 8 to 10 m class telescopes. Every telescope in this class has its own system under design. They might be operational at the begining of the next century on most telescopes (Keck, ESO, Subaru, Gemini, etc). The number of actuators vary according to the type of WFS between a few ten and several hundred.

After the successfull operation of the 3.6m AO system, Adonis, for several years, ESO, in a recent agreement, has contracted the construction of its AO for the VLT to a consortium led by ONERA-INSU-Paris and Grenoble observatories. The ESO-VLT high resolution infrared camera CONICA, developed in collaboration between MPE Garching and MPIA Heidelberg, is the first VLT instrument to be equipped with this adaptive optics system, NAOS. Naos is foreseen to enter into operations by 2000.

The CFHT Adaptive Optics Bonnette, PUEO, was mounted on the telescope for the first time in early 1996 and the two first observing runs (during first semester of 1996) have shown a smooth running right from the start and exciting results in both visible and IR.The record (up to now,in average external seeing) is a FWHM in the I band of 0.068 arcseconds on a 8.6th magnitude star and Strehl ratios larger than 0.7 have been obtained in the K band. Successfull images were also obtained while guiding on the 15th magnitude nuclei of galaxies.

ADOPTICS, the adaptive optics system for the 100-inch at Mount Wilson, works in the visible at the Cassegrain focus and uses natural guide stars. Useful correction has been obtained as faint as R = 12.5 mag..and the system is yielding images with resolution (FWHM) of 0.06 arcsec. This is as good as what is obtained on "leading sites" such as Mauna Kea.

As a complement to Adaptive Optics,artificial laser stars are being developed at various locations; Most of the research deals with monochromatic artificial stars (Lick, Philips lab., Calar Alto, etc). Because such system do not allow full atmospheric compensation, improvements are under studies. Among them an original approach is developped at Lyon Observatory with the concept of polychromatic laser artificial star. A preleminary experiment was carried out in cooperation with Lawrence Livermore National Laboratory.

Substantial progress has been made in the technical developments of the MPIA/MPE adaptive optics project ALFA,to be used at the #.5m telescope in Calar Alto. This system is intended to be used with an artificial laser bacon.The laser guide star recently underwent its first tests at Calar Alto, where a sodium star was successfully created in the sodium layer about 90 km above the telescope. The adaptive optics system is currently undergoing its final stages of testing, before being installed at the telescope in early October.

A second adaptive optics system, using a laser guide star this time, is presently being implemented at the coųd focus of the 100-inch at Mount Wilson Observatory, under direction of L. Thompson from U. of Illinois.

A laser guide star adaptive optics system has been developed for the 3-m Shane telescope at Lick Observatory by a team at Lawrence Livermore National Laboratory under the direction of Claire Max. This system is based on a 127-actuator continuous-surface deformable mirror, a Hartmann wavefront sensor equipped with a 64x64 CCD camera having a 1.2 kHz frame rate and 7 electrons read noise, a 160 Mflop control computer. and a 20 W pulsed solid-state-pumped dye laser tuned to the atomic sodium resonance line at 589 nm. The prototype Lick adaptive optics system is mounted at the f/17 Cassegrain focus of the 3-m telescope. The system can feed both an optical 1024x1024 CCD camera and a near-IR 256x256 NICMOS III camera. More information can be found at the following WWW site: http://ep.llnl.gov/urp/science/lgs_www/lgs.html.

Optical imaging is a prime goal. but it is also essential to obtain spectra with spatial resolutions matching the AO systems. This is a new area for spectroscopic developments. So far, two integral field spectrographs are very close to completion for CFHT (OASIS) and ESO (3D-GraF) and should be commissionned in 1997.

2.4. INTERFEROMETRY

The CHARA interferometer is under construction at Mount Wilson Observatory. This optical inteferometer has a Y configuration of 5 to 7 telescopes within a circle of diameter 400 meters and will have limiting resolution of 0.2 milliarcseconds. The project is under the direction of Prof. Hal McAlister from Georgia State University. Initial operation is expected in the 1998–1999 period.

In addition to current interferometric work done with arrays of small telescopes in USA, Australia, France,etc.., plans to couple 8m telescopes together , and/or with small movable telescopes, are under extensive consideration at ESO and Keck. After a 2 years delay for financial constraints, the original plan was restored at ESO with the signature by ESO, CNRS, MPG of a new agreement concerning the enhancement of VLT/VLTI, which foresees the coupling of three movable 1.80m telescopes to the 8m ones.

3. Working groups

3.1. WIDE FIELD IMAGING

Chairman: H. MacGillivray, Royal Observatory, Edinburgh;
Responsible for Photographic Techniques: David Malin, Anglo–Australian Observatory.
The Wide Field Imaging Working Group, which has been in existence since 1991 (and which includes the now defunct WG on Astronomical Photography) operates four main areas of activity.

1. Sky Surveys and Patrols
2. Photographic Techniques
3. Digitisation Techniques
4. Archive and Retrieval of Wide-field data

The purpose of the WG is to integrate related technologies and scientific methods among specialists who may be active in a number of diverse areas of astronomy. The WG considers and recommends standardisation procedures for data formats and archives and disseminates information on wide field activities to all interested parties. In this context, 'wide field' is considered to encompass, but not be limited to, fields of one degree or greater.

REPORT ON PHOTOGRAPHIC TECHNIQUES (by David Malin)

Materials availablity. Though solid state electronic devices have taken over many of the detection and imaging roles in astronomy, the unique properties of the photographic process ensure its continued use, in wide field imagery, or for some large spectroscopic surveys. These applications are especially powerful when used in conjunction with sophisticated digitising machines, which provide the quantitative parameters that are so useful for large scale survey projects. However, the diminished use of photographic plates has had a major effect on their availability, and in August 1993, the principal supplier, the Eastman Kodak Company, announced that they would forthwith discontinue many of the long-established 'spectroscopic' photographic emulsions on glass that had been available for at least 50 years. This included the venerable 103a series and the more modern IIa series on which so many photometric standards were based. However, in 1995, the company decided to restore the availability of some 103a plate products.
The reasons for this sudden action were apparently largely commercial, though it was also said that some of the ingredients, especially specialised gelatins, were no longer available or in short supply, and the business volume did not justify reformulating these products. Fortunately, the company decided to continue the supply of plates of the IIIa series materials and reformulate the near IR-sensitive emulsion, type IV-N. These products remain essential for wide angle surveys using Schmidt telescopes and their demise would have terminated many important programs. On the other hand, experiments with a more widely available product, namely Tech Pan, revealed its potential for astronomy, Tech Pan has been available since about 1990 in large sheets of film. For reasons that are still not understood, glass-based Tech Pan could not be effectively hypersensitised, so until large films were available it was unusable for imaging on large, wide field telescopes. A notable development, therefore, has been the use of Tech Pan film in the UK Schmidt, where its is found to be a significant improvement over the sensitometrically similar IIIa-F.

The main problem with Tech Pan material is that there is no blue-sensitive version, so it is difficult to designing filters to exploit the blue sensitivity of the film with high efficiency and without a significant 'red leak'. Some doubts also remain regarding the large scale astrometric integrity of film-based products, especially when they are stretched to conform to the curved focal surface of Schmidt telescopes.
The demise of several long-standing emulsion types forced the evaluation of other photographic materials with astronomical potential, including products from ORWO in Germany, and from the Slavitch company in Russia. Neither source offered a competitive replacement for the discontinued Kodak products, and though the blue-sensitive Russian material NT 1-AM looked promising, supply problems precluded further experimentation. Details of these test results are available from the author.
We were pleased to hear, in early 1996, that the Eastman Kodak Company appeared responsive to the suggestion that they make a blue sensitive version of Tech Pan – 'Tech Blue', which would overcome the 'red leak' filter problem and allow the use of an efficient system where the filter defined only the short wavelength boundary, the emulsion sensitivity itself defining the redward cutoff. Such an emulsion would be very valuable, since it would work well where the night sky is darkest, in the optical 'B' band. This proposal is still being considered as this is written, in September, 1996.

Technical results. In view of the difficulty of obtaining details of a wide range of projects the following summary is likely to be incomplete and is strongly biased towards those projects with which I am most familiar. However, recent reviews by Morgan (1995) and Reid (in press), discuss broader aspects photographic astronomy, while the proceedings of a meeting on "The Future Utilisation of Schmidt Telescopes (see reference for Morgan, 1995) is a reasonably up-to-date summary of the work with Schmidt telescopes. The occasional Newsletters of the Wide Field Imaging Working Group are also a source of information on current photographic projects.
The general trends are for increasingly sophisticated digitisation of photographic data from Schmidt telescopes and greater use of archival material from these telescopes, for imaging, classification and astrometry programs. It is also increasingly clear that combining the data from several deep images is both practical and rewarding. If the data are initially taken on high signal-to-noise emulsions such as IIIa or Tech Pan, the gains are even more substantial. Much progress has been made with this in the last three years, especially with scanning machines in the UK or in Paris. In at least one field up to 60 plates have been combined in register, with impressive detections of stars to B = 25, a remarkable result for a 1.2m Schmidt telescope using the IIIa-J emulsion. This procedure has also worked well for the detection of low surface brightness galaxies using numbers of Tech Pan films.
At the Oschin (Palomar) 1.2m Schmidt, the 'new' (POSS-II) sky surveys are approximately 90 percent complete in the J and F bands and 65% complete in I. At the UK Schmidt I-band survey is about 80% complete. while a second epoch (red) and equatorial red surveys are about 90% complete. At this telescope there is also a substantial non-survey photographic program, and the UK Schmidt is about to begin a new Galactic plane and Magellanic Clouds survey, which uses a new narrow band H-alpha interference filter to exploit the excellent H-alpha sensitivity of Tech Pan film.
Finally, there is good news for plate archives. Selenium toning during or after the processing cycle seems an effective cure for 'gold spot'. This insidious oxidation reaction produces characteristic yellow areas of degradation on processed fine grain (IIIa, IV-N) plates more than a few years old. The treatment is effective even with plates where degradation has already started.

3.2. VISIBLE DETECTORS (BY MARTIN CULLUM)

Since the last report in 1994, progress in the development of CCD technology has been made on a number fronts.

Chip formats. Several major CCD manufacturers have migrated to a quasi-standard format for large area CCDs for scientific applications with 2048x4096 pixels. These chips have pixel sizes in the range 13.5 – 15 m square, have 2 readout ports on one short side and are buttable on the three other sides. This size of CCD 's satisfies a large fraction of instrumental needs, either used individually or in a 4096N or 9182N mosaic for applications requiring larger field sizes. CCDs of this format are presently

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being made by SITe (formerly Tektronix), EEV and MIT Lincoln Laboratory (MIT/LL), as well as with foundry runs from Orbit. The move towards more standardised formats is advantageous to the astronomical community as dewars and instruments need not be radically redesigned when changing from one CCD manufacturer to another. In terms of sheer collecting area, Philips has recently announced the development of a modular manufacturing technology which allows single front-illuminated CCDs to be manufactured using 6-inch wafers with up to 7000x9000 12 mu pixels. Only slightly smaller is a CCD produced by Loral with 9000x9000 8.5 mu pixels which uses the full width of a 5-inch wafer. However, since both of these very large CCDs have a limited prospect of being thinned to give a high quantum efficiency, the major observatory development programmes are tending to build large arrays from the 2k4k, 3-side buttable devices.

Earlier 2k2k CCD designs, including the 3-side buttable CCD with 15 m pixels made by Loral and thinned by the University of Arizona as well as the ubiquitous 2k2k, 24 mu CCD from SITe, are presently in widespread use at the major observatories.

Apart from large formats, there has also been considerable development in the manufacture of smaller chips for fast readout applications such as wavefront sensors for adaptive optics systems. These have formats in the range 64x64 to 256x256 pixels.

Quantum Efficiency. In the past three years the development of thinning technology has yielded improvements in quantum efficiency (QE) in both the UV and near infrared regions of the spectrum. The most significant change has been the use of high resistivity silicon to make 200–400 m thick CCDs for high QE in the near infrared. This technology, which was developed for space-based X-ray astronomy, is available from both EEV and MIT/LL. At the time of writing, only MIT/LL is making a scientific quality thick CCD for use in optical wavelengths as part of an on-going research programme.

In the UV, the highest QE values have been attained in CCDs thinned by M. Lesser at the University of Arizona (who continues to provide a valiant service to astronomers world-wide). Lesser achieves efficiencies of up to 80% in the UV by implementing backside passivation with UV flooding or with a passivated platinum film. There have also been recent improvements in the standard boron implant technique which promise quantum efficiencies between 70–80% in the 320–400 nm UV band. In general, back-illuminated CCDs intended for astronomical applications can currently be obtained from the major CCD suppliers with peak efficiencies of 70–90%. 40–60% at 400 nm and 900 nm, and about 10% at 1000 nm.

On-chip amplifiers. There has been an increasing demand for high-speed, low noise readout from CCDs for two main reasons: With the increasing size of imaging CCDs, faster readout times are required to improve the overall observing efficiency. In addition, there is an expanding requirement for fast, low noise CCDs for wavefront sensors in adaptive optics systems. A new generation of amplifiers has been developed that can achieve very low noise at standard readout speeds of 50–100 kps (kilo pixels per second per port), and moderate noise levels at 1000 kps. The best values yet achieved are from amplifiers made by MIT/LL. These achieve 1.2 electrons rms noise at 20 kps and 3.6 electrons rms at 1000 kps. EEV has also developed a high quality amplifier which is guaranteed to deliver less than 2 electrons rms noise at 50 kps, ¡4 electrons at 500 kps, and ¡6 electrons at 1000 kps. Other manufacturers are working hard to match these figures and the trend toward lower noise at high speeds is being supported by many fields outside of astronomy.

Chip architecture. In the case of three-side buttable CCDs, a classical chip architecture is no longer suitable because the amplifier would extend beyond the width of the CCD imaging area, thus resulting in a significant gap between tessellated CCDs. The manufacture of buttable chips has therefore necessitated the development of either bent amplifier designs or tapered transfer stages so that the entire readout stage can be contained within the width of the image zone. Recent CCDs developed for adaptive optics applications usually have multiple readout ports coupled to a sectioned serial register. This allows the individual ports to be readout relatively slowly (to achieve the lowest noise) and yet still achieve high frame rates. An example of such a chip is a 128x128 pixel, split frame-transfer CCD with 16 readout ports being developed for ESO by EEV.

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CCD Control systems. Traditional CCD architectures allow the use of 1 or 2 serial registers and up to 4 readout ports per chip, i.e. one at each corner. In the past the use of more than one amplifier in astronomical applications was uncommon because of the greatly increased complexity of the readout electronics required. But the use of multiple-port readout schemes can provide a valuable reduction in the overall readout time without giving a corresponding increase in the readout noise. In order to exploit the advances in chip design, the CCD control systems have also improved. The most significant advances in this area relate to improvements in system speed to work with the faster on-chip amplifiers. Speeding up a controller is no trivial matter and involves all aspects of the system design, including signal processing, clock drivers and data transmission, electro-magnetic and thermal compatibility, not to mention the impact on subsequent data processing. Some of the newest systems utilise ultra-fast fibre-optic data links to transfer gigabits of acquired data per second to remote processors. An important feature of state-of-the-art controllers is the ability to have all operational parameters fully programmable to achieve optimal noise performance with any CCD and at all readout speeds. In this way, a single control system can be used for all applications, thus saving time and money in development and maintenance. On the other end of the scale, the commercial market for low to medium cost CCD systems has also developed rapidly in the last 3 years so that CCD cameras of moderate performance are today even within the reach of advanced amateurs.

Other optical detectors.

1. Avalanche Photo-Diodes: Astronomers have long dreamed of large arrays of Avalanche Photo-Diodes [APD] which could combine the sensitivity of a CCD with the low readout noise of a photon-counting system. Sadly, large APD arrays remain a dream, but research into these detectors continues albeit with more modest goals. The most widely used APDs for astronomy are manufactured by EG&G Canada. Individual diodes have been available for some years and achieve a quantum efficiency of about 70% at 700nm. More recently, EG&G have produced quad-cell APDs which are currently being evaluated in various research groups. A key component to achieve a good dynamic range with APDs is the quenching circuit. Moreover, the development of APD arrays requires this circuitry to be integrated into the detector head as close as possible to the diode. A group at the Politecnico of Milan has considerably improved the electronics and has developed a custom IC for part of the active quenching/active reset circuitry. When used with EG&G APD diodes, this system achieves photon-pair discrimination of 38 nsec, and a dynamic range of about 5 Mcounts/second. With the use of gating electronics this range can be extended to 25 Mcounts/second. Current activities in this development programme include the production of integrated quad-cell photon counters with enhanced quantum efficiency through the use of multi-layer coatings optimised for the EG&G diodes. Several of these units, which are intended for fast image motion control, will be produced during 1997.
   Distributed arrays of discrete diodes may be produced in the near future using segmented lenslet arrays to provide essentially 100% field coverage. These could be useful for the detection of fast astrophysical phenomena over a limited field of view or for adaptive optics wavefront curvature sensors.
2. Superconducting Tunnel Junctions: Although CCDs are well entrenched as the choice optical detector for most present day astronomical observations, current research into superconducting tunnel junction (STJ) detectors at ESTEC provides a fascinating insight into possible future detectors for astronomy. STJ detectors rely on the breaking of Cooper pairs in superconducting film by incoming photons. As the energy required for this is much less than that required to generate an electron-hole pair in Silicon, the STJ can detect not only the position of an arriving photon like a CCD, but also the energy of a photon energy and its exact time of arrival. Current STJ array sizes are very small (33), and it will be some years before such detectors could be used for routine astronomical use, but they could open up largely unexplored avenues of astrophysical research as well as stimulating the development of novel instrumental concepts.

Grateful thanks are given to J. Beletic and D. Bonaccini for providing contributions to this report.

3.3. INFRARED DETECTORS (BY IAN MCLEAN)

The emphasis in IR detectors continues to be on the development of arrays. Many near-infrared arrays and a growing number of mid-infrared arrays are now in use world-wide for imaging applications. In addition, the improved performance of array detectors has led to a significant increase in the amount of infrared spectroscopy being carried out. The last report was prepared in 1993 not long after the conference "Infrared Astronomy with Arrays: The Next Generation" which was held at UCLA. At that time, the most popular infrared array detectors had formats of 256x256 pixels for near infrared work (1–5 microns) and 128x128 pixels for the mid-infrared wavelengths of 8–30 microns. Larger formats are now available. Recent developments are usually described in SPIE conference proceedings, such as Fowler 1995, but see also McLean 1994 and other references at the end.

All of the infrared array devices are essentially of the same basic "hybrid" construction, an infrared sensitive layer sub-divided into a two-dimensional grid of photodetectors connected to a matching grid of silicon transistors via indium "bumb-bonds". The detectors are either photodiodes, photoconductors, Schottky Barrier diodes or BIB detectors. The silicon readout structure contains shift registers and multiple readout amplifiers.

For the near IR the following three devices are now in very widespread use:

1. NICMOS 3 HgCdTe arrays by Rockwell (USA): These devices, developed by the Rockwell International Science Center (Thousand Oaks, CA) for NASA and the University of Arizona as part of the Hubble Space Telescope NICMOS instrument are widely used. The percentage of mercury in this semiconductor alloy determines the band gap which is equivalent to a cut-off wavelength of about 2.5 microns. Excellent dark current performance ($\ll$1 e/s/pixel) is achieved with cooling to liquid nitrogen temperatures (77 K) only. The pixels are 40 micron square and are arranged as four quadrants of 128x128 pixels so that the device has four outputs. The readout multiplexer uses CMOS shift registers and operates with 0–5 volts clocks. Each HgCdTe detector is a reversed-biased photodiode which can be reset or read out non-destructively using a source follower per diode in the unit cell. The readout noise is typically about 30 electrons rms, but lower values are possible with multiple reads until limited by corner glow. Quantum efficiency is 40–60% from about J to K band. These devices do exhibit some charge persistence or "after image" effect which varies considerably from chip to chip.
2. InSb arrays by Hughes–SBRC (USA): These devices, developed by Santa Barbara Research Center (Goleta, CA) for ground-based infrared astronomy are also widely used, especially at infrared-optimized sites. The band gap of indium antimonide gives a cut-off wavelength of about 5.3 microns and therefore these devices are required for the L and M bands. Very good dark current performance can be obtained with sufficient cooling ($\sim$1 e/s/pixel at 35 K); either liquid helium or a closed-cycle refrigerator is needed. The pixels are 30 micron square and are arranged in a 256x256 format such that every fourth column of 256 pixels is read out by the same output line, so that this device has four outputs also. The readout multiplexer uses PMOS registers and operates with −3 to −7 volt clocks. Each InSb detector is a reversed-biased photodiode which can be reset or read out non-destructively using a source follower per diode in the unit cell. The readout noise is typically about 40 electrons rms, but lower values are possible with multiple reads. Corner glow is not an issue, but a charge-pumping effect causes an effective loss of well-depth for a given applied bias. Quantum efficiency is about 80% from J to M band.
3. PtSi arrays: These platinum silicide (PtSi) Schottky–Barrier arrays have found some applications in astronomy despite having a very low quantum efficiency of about 2% in the near IR (< 4 microns). Devices of 256x256 pixels from Hughes have been used successfully by the NOAO and even larger formats from Mitsubishi have been used by Japanese and South African astronomers. Dark current is negligible with liquid nitrogen cooling. Pixels are typically about 30 microns but the "fill-factor" is significantly less than 100% in general. Low readout noise of about 30 electrons rms is common and uniformity is excellent.

While the 256x256 arrays are still the most popular, new large format near infrared arrays are now available. Rockwell makes a 1–2.5 micron array of 1024 x 1024 pixels in HgCdTe with pixels which are 18.5 micron square. These devices have already been used in cameras by the University of Hawaii and the Max Planck Institute, Heidelberg. For the 1–5 micron range, Hughes–SBRC now make a 1024 x 1024 InSb array with 27 micron pixels. This devices has been tested in a camera and a spectrograph at NOAO. Both arrays are arranged in 512x512 quadrants. The HgCdTe array has only four outputs, but the InSb array has 32 outputs.

At longer wavelengths, blocked impurity band (BIB) devices are taking over from photoconductors. BIB devices were invented by Rockwell, but are also available from other companies. The generic term for these devices is Impurity Band Conduction (IBC) devices. Commonly used detector materials are arsenic doped silicon (Si:As) and antimony doped silicon (Si:Sb), which cover the range 8–28 and 8–38 microns respectively. In the USA, both Rockwell and Hughes provide formats of 128x128 pixels and there are now many mid-infrared cameras in use with these formats. Also, "deep-well" devices designed for high background applications have been made in Europe by LETI–LIR with formats of 64x64 pixels and have been used regularly at the CFHT and ESO telescopes. All of these detectors require much lower temperatures (5–10 K), implying the use of LHe, and all have multiple readout amplifiers (usually one per row).

More recently, IBC devices with formats of 256x256 pixels and many readout amplifiers have become available. Rockwell provides information on its World Wide Web site.

Finally, work is continuing on quantum-well devices and on gallium-doped germanium arrays for the far infrared.

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