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COMMISSION 9: INSTRUMENTATION AND TECHNIQUES
(INSTRUMENTATION ET TECHNIQUES)

PRESIDENT: Ian S. McLean
VICE-PRESIDENT: Ding-Qiang Su
ORGANIZING COMMITTEE: Thomas Armstrong, Noah Brosch, Martin Cullum, Michel Dennefeld, George Jacoby, Carol Jordan, Gerard Lelievre, Shiro Nishimura, A.K. Saxena, William Tango & Milcho Tsvetkov

1. INTRODUCTION (I. S. McLean)

The last triennium, and coincidentally the last few years of the 20^{th} century, has been a most remarkable time for Commission 9, and for astronomy in general. Ground-based astronomy in particular has received an enormous boost due to the arrival of an astonishing array of new telescopes, novel instruments and innovative techniques. For those of us closely involved in developing new observatories, instrumentation or detectors, the last few years have been rather hectic! As an astronomer with a long-time interest in the development of new instruments, what amazes me is the breadth of technology and the visionary scope of all these incredible new achievements. Many of the very large 8–10 meter class telescopes are now coming into full operation - yet, just as this is happening, numerous smaller "survey" telescopes are providing a wealth of new sources. Adaptive optics is being practiced at many sites and diffraction-limited imaging from the ground is now a reality. Several optical-IR interferometers are now working and more are coming along very soon. Detectors continue to get bigger and better, especially for the infrared, and instrumentation is increasingly more sophisticated, complex and efficient. Remote observing, robotic telescopes and global networks of telescopes are common, and international collaborations are larger and stronger than ever before.

Commission 9 has three Working Groups at present; Sky Surveys, Detectors and Interferometry. Reports from these WGs are included below. The Commission also supports IAU Colloquia and Symposia which have a specific dependence on techniques and instrumentation.

2. SCIENTIFIC HIGHLIGHTS 1997-1999

Selecting highlights is extremely difficult when there has been so much exciting progress. Three broad categories are identified: telescopes and observatories, instrumentation, and detectors. One of the best resources for all of these areas is the proceedings of the SPIE international conference on Astronomical Instrumentation and Telescopes which was held in March 1998 in Kona, Hawaii. This wide-ranging conference covered many different aspects of astronomical instrumentation and technology from the UV to the sub-millimeter. A similar meeting will be held in Münich, Germany, in late March 2000.

2.1. Telescopes & Observatories

During the last triennium several of the very large telescopes have come on-line. The twin 10-meter, segmented-mirror, telescopes of the W. M. Keck Observatory on Mauna Kea remain in the vanguard. The second Keck telescope came on-line quickly and during the last two years it has received an adaptive optics system and several new instruments (NIRSPEC

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and ESI). Both of these telescopes have played a major role in spectroscopic follow-up of the Hubble Deep Field, obtaining redshifts of fading gamma ray burst sources and searching for planets around other stars. NASA became a partner in the Keck Observatory, thereby allowing access from a wider community. The Keck Interferometer project funded by NASA was initiated and considerable site-work has already been completed.

On Cerro Paranal in Chile, the European Southern Observatory VLT project is nearing completion. The Unit 1 8.2-m telescope, now renamed Antu, obtained first light on May 25, 1998 and has received its first complement of instruments (FORS and ISAAC). Construction of the VLT Interferometer is also well under way with a goal of 2001 for completion. The six-nation International Gemini Telescopes Project (Mauna Kea and Cerro Pachon), saw the Gemini North 8.2-meter telescope dedicated on Mauna Kea in early 1999. Later that year, in September 1999, the Japanese National Large Telescope (Subaru) Project was also dedicated on Mauna Kea.

Key milestones have been reached in numerous other large telescope projects including the MMT replacement, Magellan and the LBT, and new large telescope projects such as the Keck- style Grantecan telescope for the Canary Islands have been started.

While all these large telescope projects have been nearing completion, numerous smaller survey telescopes have been producing large quantities of data. A review is given below in the Commission's Working Group report. A few highlights include the start of operations of the Sloan Digital Sky Survey (SDSS), the success of two infrared sky surveys—the Deep Near-Infrared Sky survey (DENIS) and the 2Micron All Sky Survey (2MASS)—and the spectroscopic redshift surveys with 2dF on the Anglo-Australian Telescope. Construction of a new observatory in China, the Large Sky Area Multi-Object Spectroscopic Telescope project (see below), was started in 1997. This facility will have 4000 fibers going to about 20 spectrographs.

Airborne astronomy got a new lease on life with the USA-Germany collaboration on SOFIA, the Stratospheric Observatory for Infrared Astronomy. A modified Boeing 747-SP jumbo jet will carry a 2.5-meter infrared telescope aloft.

A key result of the last triennium is the rapid pace of development of optical and infrared interferometry. Several systems are now producing astronomical results in the refereed literature and the number of conferences and meetings on interferometry has grown considerably.

The wide-spread appearance of diffraction-limited imaging at ground-based observatories is yet another highlight. Adaptive optics systems are in use at many facilities, for example, the NTT at ESO, the CFHT, the Lick Observatory and the Keck Observatory. Sodium laser beacons have also made significant progress; see, for example, the results from the LLNL group.

2.2. Instrumentation

There has been an explosion in the number and type of astronomical instruments in recent years. Large CCD-based cameras and multi-object spectrographs have been developed for all the major large telescopes, and many powerful new instruments, such as 2dF on the AAT, are now in full operation. The remarkable array of 30 CCDs in the Sloan Digital Sky Survey camera is one example of the scale of modern instruments. In the near-infrared, the advent of large-format array detectors with 1024 x 1024 pixels for wavelengths less than 5 microns has enabled the development of higher resolution infrared spectrographs. Two examples of instruments in this class are the NIRSPEC high-resolution cryogenic spectrograph for the Keck Observatory which obtained first light on April 25, 1999 and the ISAAC infrared camera/spectrometer developed at ESO for the VLT.

2.3. Detectors

Detectors are described in more detail within the report from the Detector Working Group. Briefly, the emphasis with CCDs has been the development of large-format 3-side buttable chips for mosaics and methods for obtaining better blue/UV performance. Adaptive optics wavefront sensors are pushing the demand for smaller format CCDs with very low noise and very fast readout times. Two classes of near-infrared arrays with 1024 x 1024 pixels are now in operation and 2048 x 2048 chips are under development. At thermal IR wavelengths most instruments now employ 128 x 128 blocked impurity band (BIB) arrays instead of photoconductors, and 256 x 256 devices are now becoming available.

3. SPECIAL PROJECTS

The Wide-Field Plate Database: This project is an initiative of the WG on Sky Surveys and it consists of a catalog of wide-field (>one degree) photographic plates stored in various archives all over the world (a report is given below). No other special Commission projects were undertaken in the last triennium, but the commission has supported a number of applications for IAU-sponsored meetings and has encouraged international collaborations and the definition of standards.

4. WORKING GROUPS

The commission has three Working Groups at present: Sky Surveys, Detectors and Interferometry. Reports from the Chairs of these groups are included below.

4.1. Sky Surveys (Noah Brosch)

Among the highlights of the past triennium for Sky Surveys are the following. The release of the Hipparcos-Tycho data set, with parallaxes and proper motions, as well as colors and magnitudes for one million stars. Preparation for a revised version of the HST Guide Star Catalog, with better magnitudes, and re-calibration of the photometry of the Digitized Sky Survey. The Palomar I plates (POSS I) have also been scanned with the University of Minnesota APS. A catalog of stars and galaxies from the E and O plates, including positions and magnitudes (to ~0.3 mag) can be queried on-line. The Second POSS completed its data acquisition in IIIaJ and IIIaF plates in June 1999. Some plates in IVN emulsion were still needed by then. The plates are to be scanned as part of the Digital POSS project at Caltech, and the data is to be merged with the 2MASS JHK information. The 2MASS and DENIS NIR full hemisphere sky surveys are well underway and the SDSS is on line. The goal of this project, undertaken with a dedicated 2.5-meter telescope, is to cover 10,000 square degrees of the sky in the North Galactic Cap in five filter bands with $0.8''$ resolution. In addition, the Southern Galactic Cap will be surveyed in three 2.5 x 90 degree strips. A spectroscopic survey will cover the same area with a multi-fiber system. This survey will cover 900,000 galaxies to $z\sim0.1$, 100,000 red luminous galaxies to $z\sim0.4$, and 100,000 QSOs. Also in this triennium, the 2dF survey commences in earnest — with many tens of thousands of spectra already obtained. The 6df project has been funded and is being built. This multi-fiber spectrometer system will operate on the UK Schmidt telescope. A robotic H-alpha mapping telescope El Nano (The dwarf) is up and running at CTIO. In 1997 a survey of the full Southern Galactic plane in H-alpha was started at UKST using the world's largest optical interference filter in astronomy.

Other initiatives include (i) VISTA, a UK-funded wide-field survey telescope in Chile with a goal to commission by 2004; (ii) VLA FIRST, a project to cover 10,000 square degrees of the sky at 20-cm using the VLA array. The resolution is $5''$ and the typical detection limit is 0.15 mJy. A new catalog, covering about 5,500 square degrees, was released in July 1999. Eventually all the sky above declination -10 degrees will be covered; SUMSS, Sydney University Molonglo Sky Survey. A radio survey at 843 MHz done with the Molonglo Synthesis Telescope, will cover the entire sky south of declination -30° and will thus complement the NRAO VLA Sky Survey.

Other projects include, VST, the VLT Survey Telescope (*www.na.astro.it/ ~ twg/vst/*) which is in the final design stage. This is 2.6-meter telescope for high-quality imaging. The DTM, or Dark Matter Telescope, is a proposed 8.4-meter diameter telescope with a 3-degree field for imaging. SALT, the South African Large Telescope, is a proposed 10-meter class telescope patterned after the Hobby-Eberly Telescope in Texas. EIS, the ESO Imaging Survey, is a multicolor survey with the ESO NTT and EMMI instrument. The intention is to cover 24 square degrees of the sky.

The Wide-Field Plate Database: This is an initiative of the WG on Sky Surveys and it consists of a catalog of wide-field (>one degree) photographic plates stored in various archives all over the world. The database is maintained and updated by the Institute of Astronomy of the Bulgarian Academy of Sciences (Dr. M. Tsvetkov, Project Manager). The web site for the database is (*http : //www.skyarchive.org*) At present, the catalog contains information about ~450,000 plates at 88 plate archives. The catalog can be searched on-line via a VizieR interface at *http : //vizier.u – strasbg.fr/cats/VI.htx*. The Institute received recently a PSD 1010 from ESO, which will be used to digitize plates for this project.

The 2dF QSO & Galaxy Redshift Surveys (Robert J. Smith)

The 2dF QSO Redshift Survey is taking advantage of the AAT's 2-degree Field multi-object spectrographic system (400 fibres) to create a new homogeneous catalogue of 25000 QSOs. The primary aims of the survey are to use the extremely large volume and redshift range probed by QSOs to investigate large-scale structure and evolution in the Universe to scales of up to 1000Mpc. The survey covers 740 square degrees and is coincident with the 2dF Galaxy Redshift Survey. The magnitude limited ($b_J < 20.85$) QSO candidates have been colour selected in $u - b_J$ and $b_J - r$ from UKST photographic plates. Observations are currently 28 % complete (September 1999) with over 7000 QSOs having been identified. Completeness estimates show the photometric catalogue to be >90 % complete for the range $0.3 < z < 2.2$, falling to essentially zero at $z = 2.8$. A full description of the photometric input catalogue is in preparation (Smith et al in prep., Croom et al in prep.), though a brief description may be found in Boyle et al. (1999). Objects of particular interest have already been published, including radio-loud BAL QSOs (Brotherton et al 1998) and a unique "post-starburst QSO" (Brotherton et al. 1999). Also nearing completion is a paper on the QSO luminosity function (Boyle et al., in prep.). Preliminary results show that simple luminosity evolution over the range $0.3 < z < 2.5$ is still a good fit to the observations, though with perhaps no need for an evolution cut-off anywhere below $z = 2.3$ as has previously been identified (*e.g.*, Boyle et al. 1991). We also find no evidence for a steepening of the bright end slope as has been claimed for recent bright QSO catalogues such as the LBQS or HBQS. Preliminary investigations of clustering via the 3D correlation function show already significant improvements over previous QSO clustering measurements (*e.g.* Croom & Shanks 1996), and suggest that QSO clustering does not evolve strongly as a function of redshift. More detailed discussions of survey objectives and initial results may be found in Boyle et al. (1999) and in the submissions by Boyle, Croom and Smith to the proceedings of Coral Sea Cosmology Conference II (*http : //www.mso.anu.edu.au/ DunkIsland/Proceedings*). The Survey web page is: *http : //www.anu.edu.au/~ rsmith/QSO_Survey/*

References

B.J. Boyle, S.M. Croom, R.J. Smith, T. Shanks, L. Miller, N. Loaring, 1999, Phil. Trans. Roy. Soc. Lond. A, 357.

M.S. Brotherton, Wil van Breugel, R.J. Smith, B.J. Boyle, T. Shanks, S.M. Croom, Lance Miller, Robert H. Becker, 1998, ApJL, 505, 7.

Brotherton, van Breugel, Stanford, Smith, Boyle, Miller, Shanks, Croom, Filippenko, 1999 ApJL, 520, 87.

Croom & Shanks, 1996, MNRAS, 281, 893.

The 2dF Galaxy Redshift Survey (2dFGRS) aims to observe the spectra and measure the redshifts for 250,000 galaxies. The survey is being carried out using the 2dF 400-fibre spectrograph on the Anglo-Australian Telescope by a consortium of Australian and UK astronomers. The galaxy sample is magnitude limited at $b = 19.45$, and was selected from UK Schmidt plates scanned by the APM. The galaxies selected are in two contiguous strips, one in each of the North and South galactic caps, and in 100 random 2dF fields in the South galactic cap. As of August 1999, the total of unique redshifts measured is just over 50000, twice as many as in the largest previous redshift survey. Recent publications from the survey are listed below. For more information about the 2dFGRS, see our web page at *http://msowww.anu.edu.au/~colless/2dF*.

References

First Results from the 2dF Galaxy Redshift Survey, Colless M.M., 1999, Phil. Trans. Roy. Soc. Lond. A, 357, 105-116

Early Results from the 2dF Galaxy Redshift Survey, Colless M.M., 1999, "Wide Field Surveys in Cosmology", eds Colombi S., Mellier Y., Raban B., 14th IAP Colloquium, Editions Frontieres, pp.77-80

The 2dF Galaxy Redshift Survey: Spectral Types and Luminosity Functions, Folkes S., Ronen S., Price I., Lahav O., Colless M.M., Maddox S.J., Deeley K., Glazebrook K., Bland-Hawthorn J., Cannon R.D., Cole S., Collins C.A., Couch W.J., Driver S.P., Dalton G.B., Efstathiou G., Ellis R.S., Frenk C.S., Glazebrook K., Kaiser N., Lewis I., Lumsden S., Peacock J.A., Peterson B.A., Sutherland W.J., Taylor K., 1999, MNRAS, 308, 459

The 2dF Galaxy Redshift Survey: An Update, Price I., Colless M.M., Bridges T.J. and the 2dFGRS team, 1999, AAO Newsletter, No. 90, pp6,20

The 2dF Galaxy Redshift Survey - Overview, Colless M.M., 1999, "Redshift Surveys and Cosmology", Coral Sea Cosmology Conference II, Dunk Island, *http://www.mso.anu.edu.au/DunkIsland/Proceedings/Colless*

Chinese instrument for surveys (Jin Wenjing, Shanghai Astronomical Observatory)

The 60/90 cm Schmidt telescope installed 2048 x 2048 CCD at Xing-Long Station of BAO, the field of view is 10 x 10, the focal length is 1.8 m. There is an international collaboration program BATC (Beijing-Arizona-Taipei-Connecticut) for a sky survey of multi-band colour photometry for quasars. Part of the observational data can be used for precise position determination of optical counterparts of CERS.

There is also an international collaboration program between Shanghai Astronomical Observatory and Nikolaev Astronomical Observatory. The Axial Meridian Circle (AMC) of Ukraine telescope was used for observation of secondary reference stars in the fields around the ERS. The AMC was equipped with 256 x 288 CCD (FOV 9′ x 13′) during 1996-1998 and 1040 x 1160 CCD (FOV 24′ x 26′) in 1999.

The optical counterparts of 75 compact extragalactic radio sources have been observed using the four China instruments during the period from 1996 to 1999. By the AMC positions of more than 100000 observations of about 15000 secondary reference stars for declination zone from +70 to -20 and in the 12-14 magnitude range were obtained in fields around of 190 ERS.

The HI Parkes All-Sky Survey (HIPASS) (Lister Staveley-Smith)

The HIPASS survey is a 21-cm wavelength spectral survey for extragalactic neutral hydrogen in the velocity range -1200 to 12700 km/s. The observations are being carried out with the multibeam receiver on the 64-m Parkes telescope in Australia and have been underway since early 1997. HIPASS, and an associated deep survey in the Zone of Avoidance, is expected to be finished in late-1999 or early 2000. Details on the project can be found at the web site *http://www.atnf.csiro.au/research/multibeam/multibeam.html*. Also at this address, details of data availability can be found. Following a limited data release in October 1999, there will be a full release of calibrated spectral data in late 1999/early 2000. HIPASS covers the sky south of declination +2 degrees, although many parts of the sky south of +25 degrees will also be covered. The Zone of Avoidance survey covers the longitude range 212 deg to 36 deg and the latitude range -5 deg to +5 deg with five times more integration time than HIPASS.

References

Banks, et al. 1999, "New Galaxies Discovered in the First Blind HI Survey of the Centaurus A Group", ApJ, October issue.

Knezek 1999, "The Optical Counterparts to Galaxies in the Cen A Group Discovered by HIPASS", PASA, 16, 60.

Kilborn, Webster & Staveley-Smith 1999, "The HI Mass Function from HIPASS", PASA, 16, 8.

Henning, Staveley-Smith, Kraan-Korteweg & Sadler 1999, "The HI Parkes Zone of Avoidance Shallow Survey", PASA, 16, 35.

Staveley-Smith, Juraszek, Koribalski, Ekers, Green, Haynes, Henning, Kesteven, Kraan-Korteweg, Price & Sadler 1998, "New HI-detected Galaxies in the Zone of Avoidance" AJ, 116, 2717.

Putman, et al. 1998, "Tidal Disruption of the Magellanic Clouds by the Milky Way", Nature, 394, 752.

Barnes, Staveley-Smith, Ye & Oosterloo 1998, "Robust, realtime bandpass removal for the HI Parkes All Sky Survey Project using AIPS++", ADASS VII, p.89, ASP, San Francisco.

Staveley-Smith, Wilson, Bird, Disney, Ekers, Freeman, Haynes, Sinclair, Vaile, Webster & Wright 1996, "The Parkes 21cm Multibeam Receiver", PASA, 13, 243.

2-Micron All-Sky Survey (John Huchra, CfA)

The web page contains updates on sky coverage, as well as the magnitude limits and photometric accuracy being reached. About 70 % of the sky has been scanned, and about 40 % is reduced now. Detections for point sources are about $K = 14, H = 14.5 \& J = 15.1$ at 10/1 S/N (10 % photometry). Astrometric accuracy is about $0.2''$, and the existing catalog has (as of August 25, 1999) 1,4000,000 extended sources and probably 100 times as many stellar sources. The Web address is: *http://www.ipac.caltech.edu/2mass/*

The LAMOST project in China (Dingqiang Su)

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a national large telescope project which started construction in 1997 and should be completed in 2004. A special reflecting Schmidt telescope is used to observe celestial objects. The telescope has an aperture of 4 m, f ratio of 5, and a 5 degree field of view. Its optical axis is fixed and tilted 25 degrees to the horizontal that runs from south to north. The Schmidt plate is composed of 24 hexagonal sub-mirrors and the primary mirror is composed of 37 hexagonal sub-mirrors. Celestial objects are observed for 1.5 h as they pass through the meridian. The shape of the reflecting Schmidt plate has to be changed with each different declination and in the tracking process. This is achieved with active optics. The sky area to be observed is declination between -10 degrees to +90 degrees. There are 4000 optical fibers on the telescope focal surface that will lead to about 20 spectrographs. LAMOST will bring Chinese astronomy into the 21st century with a leading role in large scale and large sample astronomy and astrophysics.

The most challenging technology in LAMOST project is the active optics. Two types of active optics are simultaneously adopted on the reflecting Schmidt plate:
(a) Monolithic thin mirror active optics used on each of the 24 sub-mirrors to compensate the spherical aberration and with about 10 microns of the maximum active deformation;
(b) Segmented mirror active optics used to maintain co-focus of 24 sub-mirrors.

Another challenge is the positioning of the optical fibers. After every observation, each of the 4000 optical fibers which are placed on the focal surface have to be moved to the another position precisely for next observation, and the time limited observation schedule requires very short reposition time.

Recent progress: The image quality at the edge field of view and worst sky area is about 1.78″ . To improve this value, many aspherical lenses with 3 mm in diameter will be attached to some of the 4000 optical fibers. With about 6 microns asphericity, these lenses could compensate the residual off-axis aberrations of the optical system and obtain much better image quality, thus in any case the image spread could less than 0.6 arc seconds. At the open air, an outdoor experiment program for producing the aspherical surface and accurately measuring the wave front shape of the active reflecting Schmidt plate is in progress. The experiment is with the full scale of the sub-system of the telescope, that means with one sub-mirror of the Schmidt plate, one sub-mirror of the primary mirror and the focal plane placed at the middle of the 40 meters distance between them. The experiment is very likely to get some results in the year 2000. For segmented mirror active optics, an indoor experiment has been taken and some good results in co-focus control have been obtained.

References

Shou-guan Wang, Ding-qiang Su, Yao-quan Chu, Xiangqun Cui, Ya-nan Wang, "Special configuration of a very large Schmidt telescope for extensive astronomical spectroscopic observation", Appl. Opt. 35, pp. 5155-5161, 1996.

Ding-qiang Su, Xiangqun Cui, Ya-nan Wang, Zhengqiu Yao, "Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) and its key technology", SPIE Vol. 3352, Advanced Technology Optical/IR Telescope VI, ed. By L. M. Stepp, pp. 76-90, 1998.

The AAO/UKST H-alpha Survey (Quentin Parker)

The survey has observed 67 % of the Southern Galactic plane and 575 of the Magellanic Cloud fields with contemporaneous 3 hour H-alpha and 15 minute short (broad-band) R exposures all on tech-pan film. We expect to complete the survey by late 2000 early 2001 and within 6 months of that date release a calibrated 10 micron resolution H-alpha pixel map of the plane and clouds from SuperCOSMOS scans to the community. We anticipate an on-line atlas based at the WFAU (Wide Field Astronomy Unit) at ROE. So far even visual scanning of the films has revealed 500+ new Galactic Planetary nebulae (*cf.* $\sim$ 1000 currently known).

The USNO CCD Astrograph Catalog (Norbert Zacharias)

The USNO CCD Astrograph Catalog (UCAC) project is a high precision, astrometric survey for the 7−16 magnitude range, in the band 579−642 nm, aiming at an accuracy of 20 mas for $8 - 14^m$ stars. The project started in February 1998 at Cerro Tololo (CTIO, Chile) beginning with the South Celestial Pole area. By August 1999 over 72 % of the Southern sky has been observed in a 2-fold overlap pattern, producing 1.4 TB of compressed, raw data. A first catalog for about 20 million stars from the first 1.5 years of observing is in preparation. Positions are supplemented by preliminary proper motions obtained from Schmidt surveys.

New versions, now on the Hipparcos system, of both the Twin Astrograph Catalog (TAC) and the Second Cape Photographic Catalog (CPC2) were released by the US Naval Observatory in 1999. The TAC contains precise positions for 705,099 stars in the range +90 to -18 degrees declination to a limiting magnitude of about $V = 11$ with B and V photographic magnitudes, while the CPC2 gives positions for 274,669 stars covering the Southern Hemisphere to about $V = 10.5$. For more details on those astrometric catalogs see: *http://www.usno.navy.mil/ad/ad.html*

4.2. Detectors

CCD Detectors (Martin Cullum)

Since the last report in 1996, the process of CCD development has been to a large extent evolutionary rather than revolutionary. The area of the largest available scientific CCD chips has not changed significantly, but the commercial availability of science grade sensors with excellent quantum efficiency has considerably improved. Blue-optimised chips with a QE of 70-80 % at 400 nm and red-optimised chips with a QE of over 90 % at 800 nm have been commonly reported. Large format CCD chips from EEV in the UK, and Site in the US are most widely used in the major observatories. MIT Lincoln Labs do not manufacture CCDs commercially but have produced a number of CCD chips that are being tested at several observatories. A chip format of 2k x 4k with 15-micron pixels, buttable on 3 sides, has become fairly standard amongst the major chip producers. Lockheed-Martin-Fairchild have reported the development of a thinned 4k x 4k device and there has been some work, at EEV for example, towards CCD packaging that allows 4-side buttability. Because the supply of good commercial CCDs has improved, fewer astronomical institutes are now willing to fund CCD chip production runs at silicon foundries except for special purpose applications.

Another area where progress has been noticeable is the design on-chip amplifiers. Manufacturers such as MIT Lincoln Labs and EEV in particular have produced CCDs capable of high readout speeds with very low noise levels. Read noise levels of less than 2e$^-$ rms have been reported at speeds of 50 kpixel.sec^{-1}, and 6e$^-$ at 1 Mpixel.sec^{-1}. On-going development is expected to push the readout to even higher speeds in the near future. Parallel readout architectures have also been developed as an alternative way to improve the frame rates without sacrificing the readout noise.

One of the main drivers for high speed readout has been adaptive optics systems where wave-front sensors with millisecond frame rates and a very low read noise are desired. However, fast readout technology will also benefit users of large format CCDs and mosaics because of the saving in readout times that have a direct influence on observing efficiency. Workers at the Max-Planck Institut füer extraterrestrische Physik have recently reported the development of active pixel CCDs which could provide an interesting future alternative to conventional CCDs or avalanche photodiode (APD) arrays for applications requiring low noise, high speed readout.

The widespread availability of large format buttable CCDs had encouraged a number of observatories to construct wide field imaging cameras with a close-packed mosaic of chips in a common cryostat. Examples of currently operating systems are the 8k x 8k Wide Field Imager at ESO and the 12k x 8k CFH12K prime focus camera at the CFHT. Even larger arrays are envisaged, such as the 20k x 18k system being developed at CEA/Saclay that is also planned for the prime focus of the CFHT.

The advent of large CCD mosaics, and the consequent concentration of readout electronics, has led a number of observatories to develop new drive electronics that are more compact and less power hungry than their predecessors. In addition, as the largest envisaged mosaics will produce almost 1 Gbyte of data per integration, considerable emphasis has been placed at many observatories in streamlining and automating the data handling and reduction procedures to avoid being simply overwhelmed by data.

Specialist CCD Workshops, which have taken place at approximately yearly intervals (at ESO, Garching in October 1996 and September 1999, and on Grand Cayman Island in December 1998) have enabled CCD manufacturers and astronomical users to get together to discuss problems and developments. In addition the CCD-World email newsletter, organized and moderated by Tim Abbott at NOT, continues to provide a lively and valuable forum for those working with CCD detectors. Further information on this can be found at *http://www.not.iac.es/CCD-world/home.html*.

Infrared detectors (Ian McLean)

Mercury-cadmium-telluride (HgCdTe) detectors with short cut-off wavelengths of 2.5 microns have reached the 1024 x 1024 pixel format with the so-called HAWAII chip made by Rockwell International Science Center in the US. These detectors have 18.5 micron pixels and very low noise. Figures as low as 3 electrons rms have been measured using multiple non-destructive readouts. Several 1024 x 1024 devices have been deployed in infrared cameras over the last triennium. Rockwell International is currently developing a 2048 x 2048 HgCdTe detector and they are also working on extending the wavelength range to 5 microns. At the same time, the application of technologies such as molecular beam epitaxy (MBE) will allow the same detectors to work down to 0.8 or even 0.6 microns.

Raytheon (formerly SBRC) in Goleta, CA, has developed indium antimonide (InSb) detectors, known as the ALADDIN chips, with a format of 1024 x 1024 pixels These devices have 27 micron pixels and give very high quantum efficiency from 0.9–5.5 microns. Several large-telescope consortia organized foundry runs for these devices and InSb arrays are now finding their way into infrared cameras and spectrometers on large aperture telescopes such as the Keck, Gemini, Subaru and VLT. Raytheon is presently considering a 2k x 2k design of this detector.

At mid-infrared wavelengths, arsenic-doped silicon (Si:As) impurity band conduction (IBC) devices, also referred to as blocked impurity band (BIB) devices, with formats of 128 x 128 pixels are now in routine use in many mid-infrared cameras. These detectors cover the wavelength range from 5 to about 30 microns. Larger devices are being produced by both Raytheon and Boeing (formerly Rockwell, Anaheim, CA). Long wavelength BIB detectors with 256 x 256 pixels are also being developed for low background space applications (SIRTF).

A useful reference for current developments in infrared astronomical detectors and instrumentation are the proceedings of the 1998 SPIE meeting in Kona, Hawaii, edited by Albert Fowler of NOAO (SPIE Volume 3354).

4.3. Interferometry (J.T. Armstrong)

Over the past three years, the visibility of optical interferometry has increased substantially. While the Mark III and I2T have ceased operations, ISI and GI2T have continued to produce significant results; several of the interferometers begun in the early and mid-1990s—COAST, IOTA, PTI, NPOI, and SUSI—have grown in capabilities and have also published extensive results; and the MIRA project has moved beyond its prototyping phase. Construction on the CHARA array on Mt. Wilson, California, is well advanced. Designs for the Keck and VLT interferometers are well under way, as is the Space Interferometry Mission. Interferometry from space is now seen as a key technique for finding and investigating extrasolar planets. Conferences devoted to interferometry come more and more frequently.

The technical direction for the field is toward larger apertures (CHARA [1 m], Keck [1.8 m and 10 m], VLTI [1.8 m and 8 m], LBT [8.4 m], Magdalena Ridge [2.4 m and 0.8 m]) and toward space interferometry.

In addition, several key publications have appeared. In the refereed literature, numerous observational papers have appeared, as have descriptions of several interferometers, while conference proceedings are still the richest source of information on current developments. An interferometry fellowship program has been established by NASA, and a series of summer schools has been started by USNO, NRL, and NASA. Unfortunately, the field suffered an untimely loss in the death of J.-M. Mariotti.

An excellent summary site for optical interferometry is maintained by Peter Lawson at JPL, with links to the interferometers listed here and links to meetings, publications, and recent news. *http://huey.jpl.nasa.gov/olbin/*

Interferometers currently in operation (listed from east to west): GI2T: Grand Interferometre a Deux Telescopes (Obs. Cote d'Azur/Obs. Nice, France) currently has two 1.52 m elements, and plans the installation of a third telescope in 2001. It is the only interferometer currently working in multi-speckle mode and with (relatively) high-resolution spectroscopy. A new beam combiner (REGAIN) for two- and three-element operations at visual wavelengths has been installed; first fringes were seen in August 1999. An integrated-optics IR combiner/camera (IONIC) is under development. Recent publications include observations of the circumstellar regions around Be and B[e] stars, P Cygni and zeta Tauri, as well as observations of beta Lyrae and delta Cephei. (*http://wwwrc.obs-azur.fr/fresnel/gi2t/gi2t.html*)

COAST: The Cambridge Optical Aperture Synthesis Array (Cambridge Univ., UK) currently consists of five 40 cm elements and a four-way beam combiner operating at visual and IR wavelengths. The COAST group were the first with both three-and four-element operations. Recent results include images of Capella, Betelgeuse, and R Leonis. (*http://www.mrao.cam.ac.uk/telescopes/coast/index.html*)

IOTA: The Infrared-Optical Telescope Array (CfA, U. Mass., USA; Obs. de Paris-Meudon, France; INAOE, Mexico; NASA-Ames, USA) has been working with two 45 cm elements at visual and IR wavelengths. A third element is now installed, and a three-element observing capability is expected soon. The FLUOR (Fiber Linked Unit for Optical Recombination; Obs. de Paris-Meudon) group has been using single-mode fibers on IOTA to clean up the wavefronts, and find that the calibration variations are much reduced. Recent results include observations of the red dwarf binary Gl570B, circumstellar material around Ae/Be stars, R Leonis, and K and M star diameters. (*http://cfa-www.harvard.edu/cfa/oir/IOTA/* and *http://despa.obspm.fr/fluor/*)

NPOI: The Navy Prototype Optical Interferometer (US Naval Research Laboratory, US Naval Obs., Lowell Obs., USA) has been operating with three 12 cm elements and a 37.5 m maximum baseline since 1996; expansion to six elements (four of them 40 cm) by the end of 2000 is planned, with extension to 434 m baselines to follow. Several papers on diameters and binary orbits have appeared, as well as preliminary astrometric results. (*http://aries.usno.navy.mil/ad_home/npoi/npoi.html*)

PTI: The Palomar Testbed Interferometer (JPL/CalTech, USA) is designed as a two-element interferometer for narrow-angle astrometry using a unique dual-star feed. Currently, PTI has three 40 cm elements (elements are used pairwise). The dual-star mode for narrow-angle astrometry is still under development; meanwhile, several papers on binary star orbits and on stellar diameters have appeared. (*http://huey.jpl.nasa.gov/palomar/*)

ISI: The Infrared Spatial Interferometer (UC Berkeley, USA), operating at 11 microns, has recently installed a bank of filters and has implemented an automated guiding and tip/tilt control system at 2 microns. ISI has received funding to build a third 1.65 m element, and to extend to 75 m baseline length. Several results have appeared, including the observations of changes in the dust shell around Mira and IK Tauri, observations of NML Cygni, alpha Scorpii, and alpha Orionis, and observations of pulsating late-type stars. (*http://isi.ssl.berkeley.edu/isi.html*)

SUSI: The Sydney University Stellar Interferometer (Sydney Univ., Australia), operating with two 20 cm elements at blue visual wavelengths on baselines currently up to 80 m, is described in two recent papers. A diameter of delta Canis Majoris and a study of the atmospheric coherence time have been published.
(*http://www.physics.usyd.edu.au/astron/susi/susi.html*)

MIRA: The Mitaka optical-InfraRed Array MIRA-I (National Astronomy Observatory, Japan) consisted of two 25 cm elements on a 4 m baseline, and served as a prototype for MIRA-I.2 (which includes baseline metrology for astrometry), and for MIRA-II, MIRA-III, and MIRA-SG, a sequence of proposed larger arrays in Japan and on Mauna Kea. Fringes on Vega were detected in June 1998. MIRA-I was closed in March 1999 to make way for MIRA-I.2 with a 30 m baseline. (*http://tamago.mtk.nao.ac.jp/mira*)

Interferometers under construction or in the design stage:

CHARA: The Center for High Angular Resolution Astronomy (Georgia State Univ., USA) array will consist of six 1 m telescopes with a maximum baseline length of 400 m, located on Mt. Wilson, California, and working at visual and K-band wavelengths. The beam-combining laboratory, six telescope enclosures, and the machine shop are complete. The first telescope was installed in March, 1999, with six more to be installed later in 1999 and an eventual goal of eight telescopes. Internal H-band fringes were seen in August 1999, and images of Jupiter with the first telescope, were seen in October 1999. Full operations are expected in early 2001. The Web site has an exceptionally rich collection of technical documents. *http://www.chara.gsu.edu/CHARA/Array/chara_array.html*

Keck: The Keck Interferometer (CalTech, JPL, CARA; USA) will consist of four 1.8 m telescopes that can be used with the two 10 m telescopes at near- and mid-IR wavelengths. The maximum baseline will be 140 m. The implementation phase has started. Test siderostats and underground light pipes connecting them to the beam combining room are being installed. The optical system will be installed and verified with the test siderostats in the spring and summer of 2000. *http://huey.jpl.nasa.gov/keck/*

VLTI: The Very Large Telescope Interferometer (ESO) will consist of several 1.8 telescopes and the four 8 m telescopes, with a maximum baseline of 200 m and operating at near- and mid-IR wavelengths. The first two 1.8 m telescopes are expected on Paranal in mid-2002, but will be preceded by test observations with siderostats. *http://www.eso.org/projects/vlti/*

LBT: The Large Binocular Telescope (Arcetri, Italy; U. Arizona, Arizona State Univ. USA; MPIfA Heidelberg, Landessternwarte Heidelberg, Astrophysikalisches Institut Potsdam, MPIfEP Munich, MPIfR Bonn, Germany; Ohio State Univ., Univ. of Notre Dame, USA) located on Mt. Graham, Arizona, USA, will consist of two 8.4 m primaries with a center-to-center separation of 14.4 m. Interferometric imaging capabilities over the 0.4 to 400 micron range are planned. The enclosure construction and first primary mirror are well under way. Operations with two primaries are expected in 2004. *http://medusa.as.arizona.edu/lbtwww/lbt.html*

MRO: The Magdalena Ridge Observatory (New Mexico Tech, New Mexico State Univ., Univ. of Puerto Rico, Univ. of Alabama Huntsville, USA) obtained initial funding in October 1999 for a three-element interferometer (2 x 2.4 m plus 0.8 m) on Magdalena Ridge, New Mexico. *http://www.physics.nmt.edu/research/MRO.html*

The number of optical-interferometry related conferences and schools has risen sharply. In 1999, the International School of Space Science (L'Aquila, Italy), the Michelson Interferometry Summer School (Pasadena, CA, USA), and the Forum PNHRAA (Grenoble) were held to acquaint the wider astronomical community with optical interferometry, and meetings on OI were held at Dana Point, CA, and Antofagasta, Chile. The SPIE continues its bienniel series on optical interferometry with a meeting in Munich in March, 2000. The proceedings of the 1998 meeting (SPIE Proc. 3350, R.D. Reasenberg, ed.) in Kona, Hawaii, and the proceedings of the Dana Point meeting (ASP Conference Series, in press) are the best sources of current status and technical developments. A current list of meetings can be found at *http://huey.jpl.nasa.gov/olbin/meetings/*.

Peter Lawson has published a collection of historical interferometry papers in the Milestone Series of the SPIE: Selected Papers on Long Baseline Stellar Interferometry, ed. Peter R. Lawson, Volume MS 139 in the Milestone Series of Selected Reprints. SPIE Optical Engineering Press, Bellingham WA, USA. In addition, we present a very short list of publications below:

The Navy Prototype Optical Interferometer. J.T. Armstrong et al. 1998 ApJ, 496, 550

The Sydney University Stellar Interferometer I: The Instrument. J. Davis et al. 1999, MNRAS, 303, 773, and The Sydney University Stellar Interferometer II: Commissioning observations and results. J. Davis et al. 1999, MNRAS, 303, 783

The Palomar Testbed Interferometer. M.M. Colavita et al. 1999, ApJ, 510, 505

The GI2T Interferometer on Plateau de Calern. D. Mourard et al. 1994, A & A, 283, 705-713

A few scientific/technical milestones:
The first images from an optical aperture synthesis array: mapping of Capella with COAST at two epochs. J.E. Baldwin et al. 1996, A & A, 306, L13
The surface structure and limb-darkening profile of Betelgeuse. [COAST] D. Burns et al. 1997, MNRAS, 290, L11
Deriving object visibilities from interferograms obtained with a fiber stellar interferometer. [FLUOR/IOTA] V. Coud du Foresto et al. A & Asupp, 121, 379

Astrophysical results in refereed journals have become too numerous to list here. Key topics include compendia of stellar diameters; binary star orbits; stellar shape, limb darkening, and surface structure; and circumstellar material around Be stars and Mira variables. See Peter Lawson's Web site for a list of recent publications and for links to the various groups.

4.4. Major Scientific Conferences 1997-1999

A few of the major events are listed here:
1) SPIE conference in Kona, Hawaii 1998
2) H-alpha survey workshop (wide field surveys). Sydney, April 1997. Refereed proceedings published in 1998, PASA 15, 1-166.
3) ISM conference (large area optical/radio surveys covered), Penticton BC, Canada, August 1998.
4) Fibre-Optics in Astronomy III, Tenerife, Spain, Dec. 1997. Covered new fibre instrumentation including 2dF and 6dF. Proceedings published: 1998. ASP Conf. Ser. 152.
5) Looking Deep in the South. Sydney, Dec 1997. Published 1999, ESO Astrophysics Symposia.
6) LSB Galaxy Conference, Cardiff, 1998 (Proceedings published in 1999).

Ian S. McLean
President of the Commission

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