I. *TELESCOPES AND INSTRUMENTATION*

a) *Invited and oral contributed papers*

DETECTOR DEVELOPMENTS FOR SMALL TELESCOPES

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ABSTRACT. We describe the performance expected from a new generation of CCD imagers being developed by Tektronix, and we indicate the types of applications, instruments, and computer systems that can best take advantage of these devices on telescopes both large and small. Since these new detectors will be able to reach very faint limits even on small telescopes, we also describe cost-effective television viewing systems suitable for object acquisition and guiding.

1. RESEARCH PHILOSOPHY

For several types of research, small telescopes are limited only by the imagination and energy of the users, and by the detectors and instruments that are available. Since the budgets for most small telescope installations are rather limited, the instrumentation and therefore the types of scientific applications must necessarily be limited as well. In this case the following strategy makes sense: choose a research area that is suitable for the interests and abilities of the scientific users, and for the characteristics of the site. At any time, concentrate on just one or two research projects. Build an instrument system that is optimized for these projects. Support a continuing program of improvement to the instrument, the detector system, the computers, and the software. Over the long term, let the instrument system evolve to match the evolution of the particular research projects being carried out.

It is our opinion that often insufficient funds and resources are budgeted for the instrumentation compared to the telescope facility itself. Plan on spending as much (or more!) on the initial investment in the instrument, detector, and computer systems, and budget as much for the continuing development of these systems as for the operation of the facility.

At the Harvard-Smithsonian Center for Astrophysics (CfA) we have tried to practice what we are preaching here. Over the past several years the research areas that we have emphasized at our 1.5-m telescopes have involved redshifts of galaxies and precise radial velocities of stars. These areas complement each other well, because the galaxies are observed in the dark of moon, while stars are observed during bright

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time. The two capabilities use the same detectors and computer systems, and very similar reduction software. The main difference is that an echelle spectrograph is used for the stellar work instead of the galaxy spectrograph.

A large project that has utilized this capability is the CfA Redshift Survey and extensions (*e.g.* see de Lapparent, Geller, and Huchra 1986) which is having a major impact on observational cosmology and our view of the large-scale structure of the universe. Another is a survey of halo stars, which promises to make important contributions to our understanding of the structure of our galaxy (Carney and Latham 1985).

For some observatories the above research philosophy may also make sense for large telescopes. Many of the important advances in astronomy have come from major, long-term survey projects, where the work goes much more efficiently if a large fraction of the telescope is dedicated to the program.

2. CCD DETECTORS

Optical astronomy is on the threshold of a major observational revolution. A new generation of charge coupled devices (CCDs) is being developed by Tektronix, and the first devices will see operational use at telescopes starting in 1986. To set the perspective of why we think these new detectors will prove to be revolutionary, we first review the characteristics of the CCDs now in common use in astronomy.

2.1. CCDs Now in Use

CCDs manufactured by General Electric Corporation Ltd (GEC), Radio Corporation of America (RCA), and Texas Instruments (TI) are now in fairly common use at telescopes. The characteristics of these devices are summarized in Table I.

All three are buried channel devices, an architecture which allows good charge-transfer efficiency (CTE) and low dark leakage. In practice the charge transfer on some of the GEC chips is quite clean and well behaved, but the RCA has poor transfer at low light levels, when the charge in a pixel is less than about 1000 electrons. The TI has some idiosyncracies in its design that degrades the charge transfer at low light levels unless special wave forms are used for the clocking signals.

These chips use three-phase, three-level polysilicon gate structures. If the device is unthinned, as in the case of GEC, then it must be illuminated through the gate structure, with large absorption losses as a result. This is why the GEC chip has no blue sensitivity, and rather mediocre response in the red. To get blue and near-ultraviolet response, the chip must be thinned and illuminated from the back. The amount of thinning is rather critical, because there is a strong wavelength dependence on the depth that photons penetrate into silicon before being converted to charge. Both the RCA and TI chips are thinned, but the mounting scheme is quite different. The RCAs are mounted on a glass substrate, while the TIs are stretched as a thin membrane across a frame. As a result the RCAs are quite flat, while the TIs are usually bowed and wrinkled in a way that can change as they are cooled to operating temperature. This effect is large enough to degrade the resolution in very fast cameras, simply because the depth of focus is less than the variation in depth on the chip.

Table I. Characteristics of CCDs Now in use.

Manufacturer	GEC	RCA	TI
Columns x Rows	385 x 576	320 x 512	800 x 800
Pixels, mm	0.022 x 0.022	0.030 x 0.030	0.015 x 0.015
Size, mm	8.4 x 12.7	9.6 x 15.4	12.0 x 12.0
Area, cm^2	1.1	1.5	1.4
Charge transfer	Good	1000 e^- thresh	Good with tricks
Illumination	Front, thick	Back, thin	Back, thin
QE 400 nm	0%	40%	40% (UV or NO)
QE 700 nm	40%	80%	65%
Flatness	Good	Good	Marginal
Availability	Yes, but ...	No !	No, but ...

The RCA chips win very high marks for their outstanding quantum efficiency. Two factors contribute to the extra-high sensitivity in the red. First, the chip is illuminated through the glass substrate, which gives a graded change in index of refraction from vacuum to silicon, which has an index of around 4. Second, apparently RCA has some kind of surface treatment that gives significant gains not realized by TI.

Unfortunately the RCA chips are plagued by high readout noise. This, together with the low-level charge transfer problems, makes the RCA chip a relatively poor performer for spectroscopy. However, the excellent quantum efficiency makes it a winner for deep wide-band imaging, where the sky exposure brings the charge in every pixel well above the threshold needed for good charge transfer.

On the TI chips the blue and ultraviolet sensitivity is quite low, usually well below 10%, unless the accumulation layer is charged up with a technique such as flooding with hard ultraviolet light under modest vacuum during cool down, or chemical activation with nitric oxide gas at low partial pressures. With such treatments the blue response is quite similar to that of the RCAs, and much better in the ultraviolet below about 3600 A, where the glass window on the RCA begins to attenuate seriously.

2.2. Availability

Unfortunately none of the above devices are readily available. Chips can be ordered from GEC, but very few new devices suitable for astronomy have been produced or delivered for the past two years or so. RCA recently announced that their product is discontinued.

The situation with the TI 800 x 800 chips is rather more complicated. TI developed these devices for Space Telescope (ST) but chose not to manufacture any more after the ST contract ended a few years ago. In 1982 we learned that there were several dozen packaged chips that had been rejected for the Space Telescope program. A consortium led by Don York arranged through NSF for a dozen of these reject chips to be made available to a few major observatories. About ten of these chips were finally released in 1984, and most of them are now in use. Attempts to obtain release of additional chips has been thwarted by NASA's decision to build a second Wide Field/Planetary Camera, and essentially all the finished chips have been reserved for this project. However, there exist literally thousands of chips in various stages of completion, mostly unthinned and still on their wafers. In principle it should be possible to carry these chips to completion, perhaps even with a higher yield than the very low success rate experienced in the ST effort. NSF is considering a proposal for a program to complete additional TI chips.

2.3 Tektronix CCDs

More than three years ago Tektronix (Tek), Inc., Integrated Circuits Operation, P.O. Box 500, MS 59-420, Beaverton, Oregon 97077, telephone (503) 627-6101 embarked on an ambitious program to develop a new generation of large scientific imagers. Tek had been working on integrated circuits for more than ten years, and had already demonstrated impressive capabilities for in-house applications. The decision to develop a new line of high-end CCDs for external scientific markets was one of the first examples of a fundamental shift in Tek corporate policy to support venture developments for markets outside the company.

In a key move, Tek was able to hire Morley Blouke, the engineer who had led the technical development of the 800 x 800 CCDs at TI. At Tek, Morley has been able to pick up where he had left off with the ST effort, correcting errors known to exist in the TI design and process. Morley and the team at Tek are dedicated to making imagers that will satisfy the astronomers, partly because they are interested in astronomy, and partly because they know that if they can satisfy the astronomers, they can satisfy anyone. This situation is reminiscent of the symbiosis between the astronomers and E. C. Kenneth Mees at the Kodak Research Laboratories and the development of the special photographic plates used by astronomers.

The general characteristics of the Tek CCDs are summarized in Table II, with additional comments about specific characteristics in the following sections.

2.3.1. *Pixel size.* A pixel size of 0.027 x 0.027 mm was chosen for the Tek CCDs, partly to obtain a large full-well charge, 700,000 e^-, and thus a large dynamic range, and partly with an eye towards the giant telescopes of the future, where the focal lengths will be very long even with extremely fast optics.

2.3.2. *Array size and format.* The most important thrust of the Tek project is to build CCDs far larger than any other integrated circuit yet attempted. The CCDs now in use have areas of about 1.5 cm^2, while Tek is building their standard devices in two sizes, one with an area of

1.9 cm^2, and the other with the astounding area of 30.6 cm^2. Previously the largest CCD attempt that we know about was an effort at GEC supported by the Anglo-Australian Telescope, with an area of about 9 cm^2, and although this effort has produced one or two devices that make images, they are not suitable for astronomical use. The geometries of the two standard Tek configurations are summarized below:

Pixel format	512 x 512	2048 x 2048
Chip size, mm	13.8 x 13.8	55.3 x 55.3
Chip area, cm^2	1.9	30.6

2.3.3. *Charge Transfer*. The specification on the efficiency of charge transfer is 0.99999 or better. This is barely good enough for the large chip, where the charge from a pixel in the far corner must be shifted up the parallel register 2048 rows and then across the serial register 2048 columns before it reaches the on-chip output amplifier. An efficiency of 0.99999 raised to the power 4096 is 0.96, which means there would be a multiplicative shading of 4% from the corner opposite the output amplifier.

2.3.4. *Quantum efficiency*. The Tek CCDs will be available both thick for front illumination, and thinned for back illumination. Eventually the blue-ultraviolet quantum efficiency of the thinned chips should be about 40% with no special treatment required. However, for the chips produced initially it will probably be necessary to invoke the ultraviolet flooding or NO gas treatments that have proven so effective with the TI 800 x 800 chips. In the red the quantum efficiency of early production chips may not exceed 50% by very much. Within a year or two Tek hopes to offer a coating service that should increase both red and blue sensitivity.

Table II. Summary of the general characteristics of the Tek CCDs.

Pixel size	0.027 mm
Full well charge	700,000 e^-
Charge transfer	0.99999
Illumination	Front thick, or back thin
QE at 400 nm (thin)	40% (may require UV flood or NO)
QE at 700 nm (both)	50% (higher with coatings)
Flatness, mm	0.001 local, 0.05 global

2.3.5. *Mounting*. All the Tek chips will be mounted on a kovar substrate. The original plan was to use a ceramic substrate, but tests showed that this material resulted in spurious dark events due to radioactive decays.

The mounting scheme makes it possible for the Tek chips to be quite flat, an important characteristic when the chip is illuminated by very fast optics with a shallow depth of focus. The substrate also provides an important heat conduction path during cooling. Indeed, the package is robust enough to survive extreme temperature cycling, such as immersion in liquid nitrogen.

2.3.6. *Amplifiers*. The Tek chips have a serial-parallel-serial architecture, so that they can be clocked to either of two different amplifiers located at opposite corners of the array. One of the amplifiers is meant for high-speed readout at video rates, so that an image can be read in a second or less. The other amplifier is optimized for slow--scan low-noise operation, and would normally be used to read a science image. The slow amplifier has already been demonstrated to achieve a readout noise of better than 10 e^-, and the goal is to achieve 3 e^- or less with further development in the future. The fast amplifier has a readout noise of about 20 e^-, which is quite good considering the high speed of operation.

Amplifier	Slow	Fast
Read rate	50 kHz	10 MHz
Read time 512/2048	5 s / 10 s	0.03 s / 0.4 s
Read noise	10 e^-	20 e^-

3. APPLICATIONS AND INSTRUMENTATION

The development of the large Tek CCD is such an important advance in optical detectors that we expect a whole new generation of instruments will be designed around it, both for direct imaging and for high- and low-resolution spectroscopy.

3.1. Direct Imaging

In this section we make some general remarks about the types of imaging applications that we think the large Tek CCD will be likely to see on various sizes of telescopes. As a guide to these remarks, we outline in Table III the relationship between the angular size of a pixel, the field of view covered, and the focal ratio required for the imaging optics as a function of telescope diameter.

The first, rather obvious conclusion that can be drawn from Table III is that giant telescopes will never be used to survey large areas of the sky at low resolution, since this job can be done in the same exposure time using a small telescope with the same focal ratio but wider field and lower resolution. Put differently, there are no focal ratios entered in the lower right-hand corner of the table, because such fast optics are not practical.

More generally, Table III can be used as a guide for deciding what diameter telescope is most competitive by choosing the angular resolution that is needed and then selecting the telescope diameter that has the fastest focal ratio that can be achieved. Of course, the actual resolution achieved can be no better than 2 or 3 times the pixel size. For projects at a given resolution, the telescope with the fastest possible optics, *i.e.* with the largest possible diameter, will require the shortest exposure times.

Table III. Focal ratio as a function of pixel and field size.

Pixel arc-sec	Field arc-min Chip 512	Field arc-min Chip 2048	F/ratio Telescope Diameter, m 1/4	1/2	1	2	4	8
1/4	2.1	8.5	100	50	25	12	6	3
1/2	4.3	17	50	25	12	6	3	1.5
1	8.5	34	25	12	6	3	1.5	
2	17	68	12	6	3	1.5		
4	34	136	6	3	1.5			
8	68	273	3	1.5				

However, smaller telescopes can be competitive whenever the exposures are short, when the elapsed time for an observation is dominated by overhead. This will normally be the case for brighter objects, especially when the objects are scattered all over the sky.

Monitoring projects also seem suitable for small telescopes, although here the reason is not so apparent from Table III but seems to depend more on the tastes of time allocation committees and the flexibility of scheduling the actual observing time.

The small Tek CCD can be competitive for isolated objects or spectroscopic studies involving isolated spectral features. The combination of a small chip on a small telescope thus seems best suited for monitoring of isolated bright objects, especially spectroscopic monitoring of isolated spectral features.

The niches that we see for CCD imaging with different diameter telescopes are summarized in Table IV.

Table IV. CCD Imaging Niches for Different Telescope Classes.

Giant	4-8 m	Very faint QSOs, stars, and other point sources. Excellent seeing is critical.
Large	2-4 m	Faint galaxies; surveys of faint QSOs and stars.
Medium	1-2 m	Surveys of galaxies; surface photometry of extended objects; monitoring.
Small	<1 m	Wide angle surveys at low resolution; surface photometry of very extended objects at low resolution; monitoring bright objects.

3.2. Spectroscopy

The potential of the large Tek CCD for spectroscopy is enormous and varied. Undoubtedly many spectrographs will be designed specifically around this detector. We mention here just two examples; a new high-resolution big-beam echelle spectrograph, and a lower-dispersion spectrograph for measuring the redshifts of galaxies. To provide a perspective on the improvement that these instruments should provide, we compare the expected performance to that of existing workhorse spectrographs now in use at Mt. Hopkins.

3.2.1. *High-resolution big-beam echelle spectrograph.* Because the large Tek CCD has so many pixels, it is feasible to build a grating cross-dispersed echelle spectrograph that gives a factor of two in wavelength coverage with a pixel size of about 2 km s^{-1} and a resolution of roughly 5 km s^{-1} more or less independent of wavelength in the range 3,100 to 10,000 A. There are even enough pixels to give some sky coverage between orders for point sources. For the largest echelle gratings now available the entrance slit can be as wide as about 1 arc sec even on a giant telescope.

For projects where wide wavelength coverage is needed, this instrument would provide a spectacular improvement over the echelle spectrographs and photon-counting Reticons now in use at CfA (Latham 1982). Instead of covering just 3000 km s^{-1} of spectrum in a single order, the Tek CCD would improve the spectral coverage by a factor of 50! In addition there is an important gain expected in the detective quantum efficiency (DQE). The measured peak detective quantum efficiency (DQE) of the photon-counting Reticons is only about 0.11 (Latham 1982), so just the higher quantum efficiency of the Tek CCDs should give at least a factor of five at all levels of signal to noise except the very lowest. Just as important, the Tek CCD would extend the wavelength coverage into the ultraviolet, an extremely important region that is not covered by our photon-counting Reticons because of the low ultraviolet transmission of the input fiber-optic face plates.

On a large telescope such as the MMT, this spectrograph could be used for detailed abundance studies of faint stars such as dwarfs in globular clusters and giants in other galaxies. An especially exciting application would be for high signal-to-noise studies of weak absorption lines in high redshift QSO's. Such studies could use much weaker lines to study the abundances of a wide variety of elements in different stages of ionization, thus giving a much clearer picture of the chemical composition in primordial intergalactic gas clouds and the halos of galaxies at much earlier times in the history of the universe.

On smaller telescopes this spectrograph would be a powerful tool for studying the chemical abundances in brighter stars and in the interstellar medium of our galaxy.

3.2.2. *Galaxy spectrograph.* We would also like to build a CCD galaxy spectrograph to replace the Z-Machine that has been used for the CfA Redshift Survey. Once again we would get at least a factor of 5 improvement in peak quantum efficiency, plus extended wavelength coverage into the ultraviolet so that the H and K lines of ionized calcium could be included. In addition, the two dimensional coverage would allow imaging along a tall slit, thus giving optimum coverage of extended objects and the nearby sky. This is worth at least a factor of root two, just by the better sky subtraction that it allows. In crowded fields of galaxies, a multiple slit could be used to observe several objects at once.

This spectrograph would allow a medium telescope such as the 1.5-m Tillinghast Reflector at the Smithsonian's Whipple Observatory to extend the CfA Redshift surveys to the limit of the Zwicky Catalog and well beyond. The tall-slit capability would also be useful for mapping velocity fields in extended galaxies and for spectrophotometry of supernova remnants.

4. COMPUTER SYSTEMS

The large Tek CCD will present a major challenge to modern computer hardware and software systems. At 16 bits per pixel, one frame will comprise 8 MBytes, and with improved readout noise the full dynamic range can potentially go as high as 17 or 18 bits. Fortunately, fast 32-bit workstations are now available, and these seem well suited for the care and feeding of the large Tek CCD at the telescope and for quick-look analysis and archiving of the data. They are also suitable for the reduction of the data later on. The investment in hardware can be similar to the cost of a large chip, when all the peripherals necessary for archiving and image display are included. The cost of software development is potentially much higher, although these costs are often hidden in the salaries of astronomers and computer programmers.

4.1. Hardware

There are many different strategies that can be adopted for the computer hardware. At CfA we have chosen a VME bus computer to provide the large amount of random-access memory needed to hold an entire frame during readout. The VME computer is in turn linked to a fully equipped VAX-Station II. In effect the VME machine serves as a memory buffer between the CCD and the VAX-Station II. The real time operating system for the control of the detector and instrument resides in the VME computer, while the astronomer works at the VAX-Station II, controlling the operation, checking the data as they come in, archiving the data, and doing some quick-look reductions.

The interface between the CCD camera and the VME computer is customized, while the interface between the VME machine and the VAX-Station II uses DRV11W boards for fast data transfer and RS232 serial lines for control.

4.2. Software

At CfA we have chosen to run the VAX-Station II under a version of UNIX, rather than under VMS. The reason is that VMS is a proprietary operating system that can not normally be transported to other computers. In contrast, UNIX is an operating system that is being implemented and supported on all the 32-bit workstations. By adopting UNIX we leave open the possibility of simple conversion to a future workstation that is not manufactured by Digital Equipment Corporation.

For image processing and data reduction we hope to run under IRAF, since this promises to be the environment of the future for most astronomical computing centers, including NOAO and STSI. Early pre-release versions of IRAF have been somewhat disappointing, but we assume that this can only get better. The goal is to be able to take advantage of applications programs developed elsewhere, and to provide the same computer environment used at the major centers so that users will be familiar with the software. All applications developed at CfA will be coded in a high level language, usually C or FORTRAN.

4.3. Low-budget approach

For many scientific applications the 512 x 512 Tek CCD should be quite adequate. In this case a low-budget approach could be adopted that would reduce the total costs substantially. The key would be to use a computer system based on a PC, both for instrument control and for image processing. The disadvantage of this approach is that IRAF and standard applications software could not be used, but the advantage would be a much lower hardware cost, perhaps 10 to 20K US dollars instead of 30 to 75K. For example, image display boards with 512 x 512 pixels and 8 grey levels are now available for PCs at a cost of about 2K, and quite large hard disks are available for similar amounts.

The real cost of this approach would be the special effort required to develop the interfaces and software systems, but this could be handled by staff members or perhaps by students.

4.4. System costs

Complete Tek CCD detector systems will not be cheap, because there are many items beyond just the chip itself. Some rough estimates of the direct costs of building a system in house are listed in Table IV, but the indirect costs for personnel such as astronomers, engineers, machinists, technicians, programmers, and students are not included.

Table IV. Rough cost estimates for Tek CCD instrument systems. In thousands of US dollars, direct costs only.

Item	512 x 512	2048 x 2048
Chip; front vs. back; quality	3 - 7	25 - 80
Dewar for CCD	4 - 8	6 - 12
Vacuum pumping station	5 - 10	10 - 15
Computer hardware	10 - 15	50 - 75
Camera electronics	2 - 4	5 - 20
TV viewing system and guider	6 - 8	10 - 15
Spectrograph	10 - 30	50 - 200
Total	40 - 82	156 - 417

If an observatory does not have the technical expertise to build a CCD camera, then it will probably be possible to purchase a system commercially. However, the direct cost of the initial purchase will be higher.

5. INTENSIFIED TELEVISION VIEWERS

With modern detectors small- and medium-sized telescopes can reach so faint that object acquisition and identification can be a major problem. An intensified television viewing system can become an essential part of the total instrument system, not only because it allows the observer to see fainter objects, but also because it brings one from the cold and dark of the dome into the warmth and light of the computer room where various aids such as finding charts and coordinates of offset stars are conveniently spread out. Just as important, a television system makes it possible to implement an automatic guider.

At CfA our intensified television viewers have evolved considerably over the years. Originally we followed the design described by researchers at the Steward Observatory (Cromwell and Angel 1979; Angel, Cromwell, and Manger 1979) and used three stages of selected Varo Gen I 25 mm tubes coupled with fiber optics to a Vikon made by Teltron, essentially a vidicon with a target whose resistivity depends on charge and therefore on light level. With this readout there is an analog integration on the target that can be as long as 10 or 20 s in areas of very low illumination. For the vidicon electronics we used standard cameras made by Cohu, being careful to provide a good ground shield between the intensifiers and the front end of the camera.

More recently we have changed both the intensifiers and the television readout. We use a single stage of Varo Gen I 25 mm intensifier in front of a Varo Gen II 25 mm MCP intensifier. We have chosen a Varo Gen I tube for the first stage in order to get the highest possible DQE. According to Cromwell *et al.* (1985) MCP tubes give away nearly a factor of three in DQE because two thirds of the photoelectrons released by the cathode never make an output flash at the phosphor. The tubes are encapsulated in GE RTV 511, and the tubes are coupled with fiber optics which are glued at each joint using Lens Bond. An important aspect of the fiber-optic boules is the transparent conducting coatings, which are tied electrically to the appropriate voltages. These coatings bleed off any high-voltage leakage in a harmless way. The coating on the boule in front of the readout also protects against noise pickup.

For the power supplies we use the standard oscillators and multipliers available on special order from Varo. A 15,000 MOhm bleed resistor is used across the high voltage for the Gen I tube, and this provides a time constant of 1 or 2 s for the front tube when the power is shut off. To hold various components in place during the potting operation, we use dabs of Dow Corning 732, since it is compatible with GE RTV 511.

For the television readout we are now using Fairchild 3000F CCD cameras. These cameras come with a fiber-optic input and a compact remote head. As a result it is possible to make a very compact viewer that we have mounted in place of the standard eyepiece on our spectrographs and offset guider stages. This system can easily see single electron events from the first cathode. The output from the Fairchild CCD is very clean, and can be fed into television monitors or directly into digital electronics for integration and/or automatic guiding.

6. INFRARED ARRAYS

The technology of infrared array detectors is experiencing very rapid evolution. One of the most significant recent developments has been the commercial availability of a 58 x 62 indium-antinomide array from Santa Barbara Research Center (SBRC). The impact of this detector will be even more dramatic for infrared imaging and spectroscopy than the Tek CCDs in the optical, because these arrays will be replacing single-element detectors, thus giving an improvement of something like 3000 for many applications. In addition, it should be much easier to get good geometrical registration and photometric accuracy because the elements of the array are all exposed simultaneously. For many applications it may not be necessary to chop.

The SBRC arrays have quantum efficiencies of about 0.5 over the spectral region 1 to 5 microns. Interestingly, the noise equivalent power of individual elements on these arrays is better than for single element detectors from the same company. The first deliveries of production devices are scheduled for late 1985, at a cost of 100K each.

ACKNOWLEDGMENT

We wish to pay tribute to Peter Crawford and Charles Hughes, the two loyal members of our instrument development team who have made possible many of the systems described in this paper. We would also like to acknowledge the fundamental contributions made by Bill Wyatt to the development of our computer systems.

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DISCUSSION

Kulkarni: What is the availability of the new Tektronix chip?

Latham: The first 512 x 512 devices will be delivered this month (close to schedule). Larger devices will be available in March or April 1986.

Gaustad: Many of us not only have small telescopes but also come from small institutions without much engineering and/or technical support. Do you think CCD systems will ever get to the point where complete systems are available and the reliability is high enough that we can acquire and operate them without becoming engineers ourselves?

Latham: Yes, but large capital investment required (the RCA system costs about $US70,000).

Garrison: An inexpensive way to solve the acquisition problem for small telescopes is a 3-stage image tube eyepiece, which can be put together for ~$US1500. We have had such an "Ojo Magico" on our 24 inch telescope in Chile since 1973 and it allows us to reach 17-18 mag easily.

Latham: There are at least two advantages when the intensified viewer has a television readout. First, the observer does not have to go into the dome in order to guide. Instead she can sit comfortably in a warm room in front of her computer. Second, the television frame can easily be digitized and used for automatic guiding. For example, at our 0.6 m CCD imaging telescope, no-one guides by hand anymore. Indeed, if the television systems are not working, we consider the telescope to be down, and we fix the system before we proceed with observing.