exposures 10 and 11 obtained at 9 and 9.30 UT, respectively, did not depict the spacecraft at all, probably because most of the satellite surfaces seen from La Silla were in shadow.

3. The Deadband Violation of OLYMPUS

In the sequence of exposures obtained between April 17 and 20, 1991, a so-called longitude deadband violation of OLYMPUS was documented by chance (see Figs. 2a–f). It occurred because of altitude control problems due to onboard sensor errors. For comparison on April 10 and 11, 1991, all four spacecraft were positioned within their control boxes (see Figs. 2a, b). On April 17, 1991, OLYMPUS was already about to pass its eastern longitude limit (see Fig. 2c). It entered the neighbouring TDF control box and can be seen between TDF-1 and TDF-2 on April 18, 1991 (see Fig. 2d), and even east of both TDFs on April 19, 1991 (Fig. 2e). The following day it drifted back to its nominal control box (see Fig. 2f) where it was found inside again on April 22, 1991 (see Fig. 1). Fortunately, this "excursion" of OLYMPUS out of its control box has caused no hazard to the neighbouring TDFs. However, the control centres certainly try to avoid such contingencies during normal operations, in particular for colocated spacecraft like the quartet at 19 deg West.

The astrometric plates obtained on the geostationary satellites can be used to measure the angular distances between the spacecraft. These angles can be transformed into projected inter-satellite distances in kilometers with an accuracy of less than 1 km in geostationary orbit. This is at least of the order or even better than the accuracy of the proximity checks using radio tracking data. Therefore, the optical observations may be useful as an additional check for the orbital proximity calculations of colocated geostationary satellites.

4. Acknowledgement

I like to thank Mr. Rüdiger Knigge of the Dr.-Remeis Observatory, Bamberg, for providing me with the excellent photoprints of the original GPO plates.

Mini-Workshop on Large-Size CCDs at ESO

S. D'ODORICO, T. DUCROS, O. IWERT and R. REISS, ESO

Which is the maximum size of a high-quality scientific CCD detector that industry can now deliver? How can the UV-blue quantum efficiency of the devices be enhanced? What are the best design approaches and the limiting performance of CCD controllers? These questions are puzzling engineers and scientists who have to do with the definition, design and procurement of the detectors and their control systems for astronomical applications. Projects like the instruments for the ESO Very Large Telescope stress the need of devices of large size and state-of-the-art performance in order to take full advantage of the larger collecting area of the telescopes. To focus on these open questions and to obtain a snapshot of this fast developing field, ESO organized on June 18th and 19th in Garching a mini-workshop on "Large Size CCD". Invited were representatives from European groups with a proven experience in this field, a few experts from overseas and speakers of CCD manufacturers with an interest in the astronomy market. The workshop was organized in three sections dedicated to CCD Controllers, CCD Operation/Testing/Design and finally to Presentations from industry. The workshop programme (see box) gives titles and authors of the talks whereas the paragraphs below summarize status and highlights of the various topics, as seen through the (possibly) biased eyes of the authors.

In the field of CCD CONTROLLERS, a variety of systems have been developed at different observatories with the aim of optimizing those operating parameters which are of relevance for the astronomical applications.

The *analog section* of the controller is beside the intrinsic quality of the CCD the dominating part as for what concerns the final quality of the signal processing and the CCD scientific data. The intrinsic CCD read-out noise has been significantly improved in the last years due to the progress in the semiconductor technology and this develop-

PRESENTATIONS AT THE ESO CCD WORKSHOP

F. Bortoletto, Obs. of Padova: "Activity of the Italian CCD working group"

J. Bregman, Radiosterrewacht, Dwingeloo: "Performance of CCD controller systems built for the 4.2-m WHT at La Palma"

P. Müller, University of Bonn: "Flexible CCD Controller for BOCCIA"

C. Cara, CEA Saclay: "A high performance microsequencer based on logic cell arrays"

R. Reiss, ESO Garching: "Present and future CCD controllers at ESO"

A. Blecha, Obs. de Genève: "High level interactive control using the CCD with a small telescope"

K. Reif, University of Bonn: "BOCCIA: the Bonn CCD imaging and analysing project"

M. Roth, Munich University Obs.: "Photometric CCD test facility and telescope simulator"

P. Jorden, RGO, Cambridge: "The operation of large EEV CCDs on the WHT at La Palma"

J. Geary, Harward Smithsonian Obs.: "Custom design of CCDs for astronomy"

R. F. Nielsen, Copenhagen University Obs.: "CCD development at Copenhagen University Obs."

J. Geary, Harward Smithsonian Obs.: "Thinning of Large CCDs"

G. Weckler, EG & G, U.S.A.: "EG & G Reticon's commitment to scientific imagers – present and future status"

A. Jutant, Thomson, France: "TMS' CCD production and large CCDs"

U. Fiedler, Tektronix, Germany: "Status of the Tektronik TK 2048 imagers"

R. Bredthauer, LORAL, U.S.A.: "Large area astronomical imagers at LORAL"

P. J. Pool, EEV, U.K.: "Recent developments of CCDs at EEV"

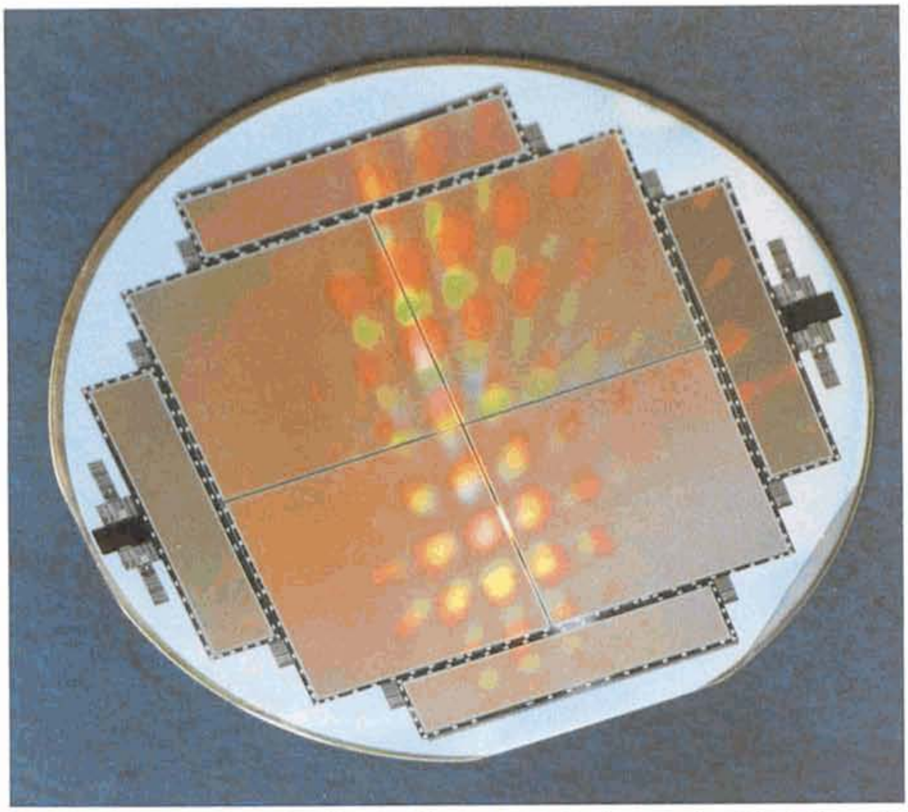

Figure 1: *How to maximize the CCD sensitive area out of a 10-cm wafer: this photograph – courtesy of Ralph Florentin Nielsen – shows a 10-cm silicon wafer by Loral (formerly Ford Aerospace) containing four 2048², 15-μm buttable CCDs prior to sawing. The CCD layout by J. Geary of the Harward Smithsonian Center for Astrophysics includes four 2688 × 512-μm CCDs for spectroscopic applications in the free space of the wafer.*

ment has forced a requirement on the analog chain to be based on circuitry design with a 1 electron equivalent noise. Overall system noise levels of 3–4 electrons have now been reached in optimal operating conditions at various observatories, approaching with CCDs the performance of photon-counting detectors. In spite of various developments concerning *analog drivers* and *video circuitry*, there has been a relative standardization of the principles of the video signal processing. Improvements are still to be expected by the use of improved components and carefully tuning of the analog modules.

Concerning the *digital controller section* the current systems (e.g. the VME-based ESO system) are routinely operating at a good level of reliability. Main disadvantages are their hardware complexity and a high power consumption, besides a great variety of sometimes not standardized interfaces to the host computer. Facing the challenge of telescope arrays like ESO's VLT, the reliability of each CCD system has to be improved drastically in order to ensure the operation of multiple systems at the various foci and telescopes.

A way to reach this aim and to improve at the same time many other features of the CCD control system is the use of Digital Signal Processors (DSPs) and Transputers (TPs) which have become commercially available during the last few years. Basically being a special species of microprocessors, TPs offer an increased capability of standard links to the outside world, e.g. the host computers, a low power consumption and less complexity of the surrounding digital circuitry. Moreover, they can also be used to collect and optionally preprocess large amounts of digital video data. The higher flexibility simplifies the implementation of multiple windows/binning, CCD mosaic operation, and total software control of all static and dynamic CCD voltages. These integrated devices are now established from different companies with standardized interfaces and seem to be well suited in leading to very small, light-weighted and reliable systems possibly attached to the CCD cryostats. Several observatories (RGO, Cerro Tololo, Padova and ESO) have now controllers based on Transputers at various stages of development. Unlike the other groups which are using TPs combined with conventional digital circuitry, ESO currently investigates the use of a combined system of TPs and DSPs. This system aims at combining the interface advantages of TPs and the quick, extremely accurate timing pattern generation of DSPs needed for CCDs.

In the section dedicated to CCD OPERATION/TESTING/DESIGN, the presentations of J. Geary from the Harvard Smithsonian Center provided updated information on two areas of crucial importance. Speaking about "Custom Design of CCDs for Astronomy", Geary pointed out that in the past the design of astronomical instruments had always to adapt to the light-sensitive area format and pixel size of commercially available CCD detectors. The development of custom-designed CCDs with guaranteed performance by the industry results in relatively high costs. Lack of the sophisticated design equipment needed for the work made it impossible for the customers to contribute in an active way to the CCD layout work. Through a collaboration with R. Bredthauer of Loral (formerly Ford Aerospace) a new approach for CCD custom design has now been successfully made, where customer and industry share part of the design and test work as well as the fabrication risk. Due to the repetitive structure of CCD light sensitive areas, the design work of the actual CCD semiconductor layout can be done for a single fraction of the CCD structure by the potential user himself on a commonly used IBM compatible PC with Autocad Software. During this design work it is possible to create or to borrow all the unique structures of the CCD (output amps, bus inputs, pixel cell). Useful is here the cooperation among potential users with their own design libraries. The resulting file is then transferred to the CCD manufacturer now acting more like a simple CCD foundry, who can edit the file with a standard text editor and introduces some replication factors for the repetitive parts (pixels, phase structures). The file (now containing the whole CCD structure) is finally converted into a CAD File for lithography with reticle masks. After the CCD production on the wafers the testing effort is again shared between the customer and the manufacturer, with the latter doing the basic on-wafer electrical testing while the first carries out the time-consuming image and full performance tests. When the wafer quality is high and the manufacturing process clean and well tested, one wafer run can produce a relatively large amount of useful devices at a low cost and with a reasonable manpower investment.

A few runs of custom-designed wafers have been successfully completed at Loral. The Danish CCD group coordinated by Johannes Andersen has shared the costs of one of these runs and is expected to receive the first CCDs by the end of the year. An example of a custom designed CCD wafer is shown in Figure 1.

What is the major drawback of custom designed CCDs? With all their interesting advantages, they remain front illuminated devices with no sensitivity in the astronomically very important UV-blue spectral region. In his second talk at the workshop, J. Geary discussed the problem of CCD thinning and the companies/laboratories who have acquired experience in this field. Various mechanical/chemical processes of whole wafer or single cut CCD thinning have been used with different degrees of success. RCA more than ten years ago, Tektronix, EG&G Reticon, Thomson and EEV in the recent past have all successfully produced thinned devices with enhanced UV-blue sensitivity. Tektronix seems at present to be the only one who regularly masters the process on devices as large as 50×50 mm. Thinning experiments are also carried out at the CCD Lab of Mike Lesser at Steward Observatory, at the lab of Danbury Optical Systems and at the David Sarnoff Research Center. These are potential addresses for CCD customers with a batch of printed wafers to thin, but the rate of success and the cost of the process are still not well defined.

The final session was dedicated to the PRESENTATIONS FROM INDUSTRY. The participants had the opportunity to hear reports on the latest products from most of the major manufacturers of scientific CCDs, as shown in the list of talks on page 43. On the size of CCDs, the trend is clearly dominated by the need to maximize the number of devices which can be fitted on 10 cm wafers to reduce the costs. This explains the success of the 2048^2, 15-μm-pixel format which allows to squeeze 4 devices on one wafer as shown in Figure 1. Improved performance was also reported due to the progress in microchannel technology for a high CTE at very low light levels and the Lightly Doped Drain (LDD) on-chip preamplifier for lower noise and higher gain.

On the performance of CCDs that a potential customer can get now off-the-shelves of industry, we suggest to contact the commercial agents of the companies. As a provisional guideline, we give below a summary of the situation as obtained from our notes on the presentations and the data sheets distributed at the workshop.

EG & G has obtained good results with 1200 × 400, 27-μm-pixel thinned devices and is currently redesigning the chip support for improved flatness.

Thomson CSF has produced thinned devices in the 512^2 format and has made plans to develop a 2048^2, 17-μm-pixel, 3-edge-buttable, thinned device.

Tektronix announced the availability of their 2048^2, 24-μm-pixel, thinned, CCD for July 1991. The device is offered with a guaranteed performance and it appears the only one of this size available on short term. The price was not named at the workshop, but Tektronix is now willing to quote it.

Richard Bredthauer of the CCD laboratory of Loral presented their results on CCDs of different formats, like the 2048^2, 15-μm-pixel and the 4096^2, 7.5-μm devices.

EEV now delivers front-illuminated devices with up to 1242 × 1152 pixels (22-μm size) and has announced a 2186 × 1152 pixel CCD, buttable on two sides. They also obtained good results in thinning smaller devices.

Beside the presentations, the workshop offered many opportunities – including a nice dinner in Munich – to discuss the various topics, and to share know-how and expertise. We have the feeling that the meeting fully met its main goals, providing an updating view of the subject and favouring the collaboration between the different groups and with the industrial suppliers.

The Use of Photography in Astronomy:

Some Thoughts about Schmidt Telescope Wide-Field Work

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1. Introduction

During the past decade, a revolution has taken place in the field of astronomical detector techniques, and astronomers all over the world are profiting from new digital devices like CCDs and photon-counting detectors. Indeed, it might appear that photography, previously so widely used in astronomy, will soon be a thing of the past in professional work, no longer of any value in front-line investigations.

Among the various types of ground-based astronomical instruments now in use, none has been more intimately connected to the development of improved photographic methods over the past decades than the large Schmidt telescopes. The future of the photographic detector in astronomy is therefore largely dependent on its useful application at Schmidt telescopes. In this article I shall explore a question that is now being posed at many observatories: is it reasonable to continue to use photographic plates in Schmidt telescopes or has the time come to aim at a rapid implementation of CCD techniques, also here?

In this connection, it should be remembered that *"an astronomical instrument is only as good as the scientific results it produces"*. This maxim is not always kept in mind and around the world there are quite a few examples of "senior" telescopes with associated methodology which for sentimental or traditional reasons continue to be in use, long after it has been shown (in other places) that their ability to produce good science of current relevance has begun to decline. Moreover, it is not always fully appreciated that it is the *science* resulting from an instrument that defines its current value in a global context, not the *technology* it employs.

In addition to the fundamental limitations imposed by the funds available in any one place, there may of course be other, perfectly valid reasons, for instance long-term continuity of observational programmes and the availability of well-established calibration systems, which makes it advantageous to keep using certain telescopes, auxiliary instruments and associated methods, also well beyond their prime years. However, in the ideal case, and certainly for most front-line research programmes, it is clear that failure to adopt new and improved technology and observational methods will eventually result in slower scientific progress and ultimately, in falling behind the rest of the world. It is also a question of the real cost of the observational data – if from a