OPTICAL DETECTOR SYSTEMS AT THE EUROPEAN SOUTHERN OBSERVATORY

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Abstract: An introductory overview is given of the recent, current, and future optical detector projects at ESO. They fall into 3 categories: (i) commissioning of detector systems with their host instruments (FLAMES, HARPS, VIMOS, and UVES blue upgrade) and VLT 2nd generation instruments (MUSE and X-shooter), (ii) the wide-angle mosaic imager OmegaCAM, and (iii) projects with a preparatory component for OWL (adaptive optics and the New General detector Controller, NGC, for both optical and infrared instruments). Their main characteristics, objectives, and their realization are briefly described.

Key words: CCDs, detector controllers, adaptive optics, cryostat operation

1. INTRODUCTION

In the 3 years since the previous status report (Baade et al. 2004), three themes have been dominating the work of the Optical Detector Team (ODT) at ESO: As always, the first and main one is the support of instrument development for ESO's La Silla Paranal Observatory (ESO established an already prevailing practice as formal policy that the detector systems for all ESO instruments are developed and built by ESO); this comprised completion and commissioning of FLAMES, HARPS, and VIMOS, the upgrade of the blue detector in UVES, and the preparation for MUSE and X-shooter as 2nd generation VLT instruments. The second theme, although logically only a subset of the first category, has been the wide-angle CCD mosaic camera OmegaCAM, owing to the large dimensions and complexity of the project. The third domain is VLT projects with preparatory elements towards Extremely Large Telescopes (ELTs). Since ELTs are fundamentally dependent on the performance of adaptive optics (AO), there is a gradual shift in emphasis from scientific imaging to signal sensing applications. Another key stepping stone in this context will be ESO's New General detector Controller (NGC).

In principle, a 4th pillar should be the contributions to the operation of ESO's La Silla Paranal Observatory. But very low downtime of the ODT systems deployed there and competent on-site support normally make this a very minor field of activity.

2. MULTI-CONJUGATE ADAPTIVE OPTICS DEMONSTRATOR (MAD)

As enabling technology for ELT's, MAD (Marchetti et al. 2004) tests two different advanced adaptive optics (AO) concepts (Shack-Hartmann and layer-oriented) for a field of view as large as one arc minute. This requires the simultaneous usage of several reference sources in the field, which in the case of this prototype system are natural stars. One of the methods employs 2, the other one 3 detector heads to be operated in tightly intertwined loops with frame rates of up to 400 Hz. Since only one of the systems will be used at a time, one FIERA is sufficient to support them. The total peak pixel rate is several Mpixel/s and so exceeds the original specification for ESO's standard CCD controller, FIERA (Beletic, Gerdes, and Duvarney 1998) by a factor of a few. Nevertheless, the read noise is less than than ~7 e^- for each of the 5 identical e2v CCD39 systems with 80x80pixels and 2-stage Peltier cooling.

Jointly with the accompanying CAMCAO camera, which deploys a Hawaii-2 detector, MAD will be commissioned at the beginning of 2006. The MAD detector system is described in more detail by Reiss et al. (these proceedings).

3. 2ND GENERATION ADAPTIVE OPTICS DETECTOR

Advanced AO systems for 8-m telescopes are based on at least 1000 degrees of freedom. As one degree of freedom requires 6x6, if not 8x8, pixels, detectors have to have of order 200 pixels on a side. Since the associated higher spatial frequencies also demand faster temporal sampling, at least 1000 frames/s have to be possible. As the result, the number of photons contained in each space-time pixel is so much reduced that the ability to detect single photons becomes vital even with very large telescopes. In spite of very short exposure times, dark current is another concern because the need to freely position the AO units anywhere in the field of view excludes the use of high-efficiency cooling systems.

Numerous European astronomy institutions, incl. ESO, have teamed up in the OPTICON network to apply for funds from the Commission of the European Union in support of the massive R&D work needed to master the above challenges. The resulting grant was supplemented by ESO and so permits a custom-designed detector to be developed. The L3Vision™ technology from e2v was chosen as the baseline, which was expanded to a split frame transfer chip design and 8 outputs in order to satisfy the high speed requirements. The first of these systems will be used with HAWK-I, a wide-field IR imager; MUSE (Sect. 5) requires the next four.

More in-depth information about the resulting CCD220, incl. a number of special options, and cross-references to other publications under the same OPTICON umbrella can be found in Downing et al. (these proceedings).

4. THE OmegaCAM WIDE-ANGLE CAMERA

The heart of the detector system of this 1^ox1^o wide-angle imager (Kuijken et al. 2004) for the VLT Survey Telescope (VST; Capaccioli et al. 2005) is a 16Kx16K mosaic of 32 e2v CCD44-82 chips. But the detector system is much more than just a passive photon sensor because it also has to provide positional and wavefront information to the telescope's tracking and active optics systems, respectively. To this effect, two auxiliary pairs of 2Kx4K CCDs are installed on the mosaic baseplate. Compared to conventional beam-splitter solutions, this has the added advantages that (a) ,by using the same filter, the same passband is used for science imaging, autoguiding, and active optics control while (b) the flux of the guide stars does not have to be shared between different tasks. Moreover, the detector system controls the instrument shutter (cf. Reif et al., these proceedings).

OmegaCAM was designed against a rather stringent set of technical specifications. Perhaps, the very small back focal distance had the single largest impact, which necessitated (i) the instrument to be partly surrounded by the M1 cell of the telescope and (ii) the detector head to be deeply imbedded in the instrument. This imposed difficult geometrical constraints on the detector head electronics. The requirement to use FIERA instead of a purpose-designed controller is an obvious one from the point of view of standardization and maintenance on Paranal but was not in all areas a booster of the design work. The mass and volume of the three FIERA and three power supply boxes (two each for the mosaic and the other one for the auxiliary CCDs) are tangible evidence of the limits the project has hit.

Substantial challenges also resulted from the survey-specific requirements that observations over the whole accessible sky and at least 10 years will still be highly homogeneous. These include very careful shielding against straylight, excellent planarity of the mosaic and its alignment with other critical planes, precise centering of the dewar entrance window (which serves as a field flattening lens), homogeneous thermal control, no cross talk between unit detectors, etc. Moreover, OmegaCAM must be very reliable because it will be the only instrument on the VST so that a failure of the instrument will inevitably imply an idle telescope.

Very careful planning and the faithful adherence to the approved plans have helped to substantially limit the number and severity of problems at later stages of the project. Because of the amount of liquid nitrogen and the large number of CCDs (the replacement of which following an accident would probably take at least 2 years), much attention was paid to the safety of operations staff as well as the equipment itself.

Iwert et al. (these proceedings) give a broad account of the history and status of the OmegaCAM detector system (the commissioning is expected for the first half of 2006). The liquid nitrogen-based, innovative cooling system, which combines the simplicity of a bath cryostat with the effectiveness of a continuous-flow cryostat, is detailed in Lizon and Silber (these proceedings) while methodological spin-offs from the extensive testing of the unit CCDs are developed by Christen et al. (a and b, these proceedings).

5. MULTI-UNIT SPECTROSCOPIC EXPLORER (MUSE)

Twenty-four integral field units will enable this spectrograph (Bacon et al. 2004) to take a full celestial inventory over a field of view of 1 armin^2, with an adaptive optics-supported spatial sampling of 0.2 arcsec ,and out to a redshift of 6. On the VLT Nasmyth platform, there will be a battery of 24 separate detector systems with 4Kx4K unit detectors (or 2x1 mosaics of 2Kx4K detectors) with 15-micron pixels. Given the objectives for the range in redshift, high red response is project critical. Equally important is that each unit detector system contributes as little to the total mass and volume as possible. Parts must be machined such that their assembly can be done without much measuring and adjusting. ESO's new VLT 2nd generation detector head will address all these points. With most possibilities for failure replicated 24 times, reliability is another design driver. Finally, MUSE will be the first optical instrument to be equipped with the New General detector

Controller (NGC; Sect. 8). A proto-type detector system must be ready in 2006 whereas the whole instrument will be installed at the VLT in 2011.

Further information about the MUSE detector system is provided by Reiss et al. (these proceedings).

6. X-SHOOTER

X-shooter (Dekker and D'Odorico 2005) will be the first instrument at ESO to bridge the 1-micron barrier. Its simultaneous wavelength coverage of nearly one dex from 0.3-2.4 micron will be effected by two optical arms (with an e2v CCD44-82 in the blue one and an MIT/LL CCID-20 in the red arm) and one IR arm (Rockwell Hawaii-2 RG). With no user definable parameters (except for coordinates and exposure time), X-shooter will be especially suitable to respond rapidly, over an extreme wavelength range, and at medium spectral resolution to ephemeral or highly variable point source. For the two optical arms, two independent virtual cameras will be defined by software on one shared FIERA hardware. Following final design review in the summer of 2005, the instrument will be commissioned in 2008.

7. CRYOSTAT CLEANLINESS AND CONTROL

7.1 Plasma cleaning

Contamination is one of the biggest threats to any optical detector system. And it is a textbook example of problems that are better prevented than solved. This rule is easily followed before the first assembly. But if the dewar has to be opened again later because something inside has to be worked on, the dilemma starts: On the one hand, there is a significant risk of contamination having occurred. On the other one, cleaning by means of the conventional washing and baking not only disrupts the project schedule but can also open a Pandora's box of new problems because disassembling and re-integrating a detector system can pose a large variety of risks.

In ESO's experience, plasma cleaning is the ideal method that not only excels as a preventive measure but is extremely effective at cleaning fully assembled cryostats. Only the detectors need to be removed because they may not withstand the high field strengths. If electronics boards can be easily removed, this is recommended. The wall of the vessel can be used as one of the electrodes, and the plasma can be ignited and observed through the dewar entrance window. One full cleaning cycle of a large cryostat such as the one of OmegaCAM (cf. Lizon and Silber, these proceedings) only takes about 10 minutes. The operating costs are nil.

The method is explained, and tests and results are described, in Deiries et al. (these proceedings).

7.2 H_2O Exorcism

The ODT test bench permits two 2Kx4K CCDs to be tested at the same time. When it was used to bake (60 degrees, 24 h) and oxygen-flush an MIT/LL CCID-20 device, it was decided to install one of the OmegaCAM CCDs for comparison. As expected, the low-frequency response non-uniformity in the UV of the latter device was removed and the lower-sensitivity regions were lifted to the higher sensitivity level of the other regions, which remained essentially unchanged. To our surprise, the QE between 300 nm and 550 nm of the OmegaCAM chip improved by a factor of up to 1.5, which was uniform over the chip surface and only depended on wavelength.

The still limited experience obtained so far suggests the following: The UV quantum efficiency of the OmegaCAM detector can be toggled between a low and a high state. The low state is assumed when the detector is for a while kept under normal atmospheric conditions. Baking under vacuum conditions (10^{-4} mbar) does not bring any improvement but combined with oxygen at 1 bar it does. During subsequent storage for 2 months at 10^{-4} mbar and -120^{o} C no significant degradation could be detected.

Further tests showed that the same effect as with pure oxygen can be achieved with clean, dry air. This could mean that the improvement in UV QE is not due to some chemical reaction but that the baking removes some substance from the CCD surface that in the presence of gas is not easily re-adsorbed. A plausible candidate for this substance is water. The tests will be repeated under more rigorously controlled conditions and will in particular be extended to plain nitrogen.

7.3 New house-keeping unit PULPO2

The novel concept of the OmegaCAM dewar and its large size (see Lizon and Silber, these proceedings) suggested that one should foresee a large number of temperature sensors for diagnostic purposes (vertical temperature stratification and horizontal homogeneity across the mosaic) although only 4 PT100's are used for actual thermal control. To this end, based on the well-proven PULPO house-keeping unit, an all new PULPO2 was developed which also features enhanced heating capabilities for both normal operation and contamination-preventing warm-up in case of a loss of vacuum or cooling. Other essential features are the associated issuing of alarm signals to the Paranal Central Alarm System and the precise shutter timing.

More information can be found in Geimer et al. (these proceedings).

8. NEW GENERAL detector CONTROLLER (NGC)

Between 1998 and 2008, a total of 30 FIERA and IRACE (Meyer et al. 1998) systems will have been deployed at ESO's La Silla Paranal Observatory for optical and infrared detector systems, respectively. Good performance and high reliability (the combined downtime of the FIERA hard- and software is of order 0.5%) have been demonstrated in substantially more than 10,000 nights of scientific operation. On June 30, 2005, the ESO Science Archive Facility held a total of 4.4 million raw files from the La Silla Paranal Observatory, of which nearly 100,000 were acquisition images, suggesting a similar number of targets and fields having been observed.

Nevertheless, the above sections have already identified some limitations of FIERA, which partly exist in a similar way for IRACE as well, and some more can be added to complement the list: mass, volume, heat dissipation, insufficient range and swing in voltage for more advanced detectors such as fully depleted CCDs, speed, number of channels, system noise, obsolete components, etc.

In response to these and further challenges resulting largely from adaptive optics and interferometry, ESO has decided to design and build a new-generation detector controller that not only satisfies the above requirements but will also be color blind and so serve both optical and IR detector systems. This also acknowledges the fact that two parallel successes may result in a larger total personal satisfaction but also incur two costs.

Because of its broad range of applications, the system is called New General detector Controller (NGC). A 4-channel prototype of the hardware has already successfully `seen' first light with a 256x256 PICNIC array from Rockwell as well as with a CCD44-82 device from e2v. The detailed quantitative characterization and improvement, the design and integration of a 34-channel acquisition board, the extension to the needs of adaptive optics (cf. Reyes et al., these proceedings), the development of the associated control software (see Cumani et al., these proceedings), which will include a substantial complement of test software, etc. will take most of the coming 3 years.

NGC will be in operation until at least 2015 when also the construction of the Overwhelmingly Large Telescope (OWL) could commence. It will pave the way of detector control into the ELT era, at which time it will have become clear what role ASICs will play and whether and where CMOS devices can replace CCDs.

A both wider and deeper overview of the NGC hardware is available in Meyer et al. (these proceedings).

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