ULTRASPEC: High-speed Spectroscopy with Zero Read-out Noise

Vik Dhillon[1]
Tom Marsh[2]
Chris Copperwheat[2]
Naidu Bezawada[3]
Derek Ives[3]
Andy Vick[3]
Kieran O'Brien[4]

[1] University of Sheffield, United Kingdom
[2] University of Warwick, United Kingdom
[3] United Kingdom Astronomy Technology Centre, Edinburgh, United Kingdom
[4] ESO

The commissioning of a spectroscopic version of the high-speed CCD camera ULTRACAM is described. This visitor instrument, ULTRASPEC, uses an electron-multiplying CCD for fast and low-noise read-out and was tested with the EFOSC2 spectrograph on the ESO 3.6-m.

Conventional CCD detectors suffer from two major weaknesses: they are slow to read out and they suffer from detector noise. These weaknesses combine to make high-speed astronomical spectroscopy of faint targets the most demanding of observations, where by 'high-speed' is meant timescales of tens of seconds and below.

It is possible to overcome the problem of slow speed by using *frame-transfer CCDs* and detector-limited data acquisition systems. Such an approach has been adopted by ULTRACAM, the high-speed, triple-beam CCD imager which was recently commissioned on the VLT (see *The Messenger* 121, 46). Reducing read-out noise in CCDs to negligible levels is more difficult, and has only recently been solved by the development of *electron-multiplying CCDs* (EMCCDs). These are conventional CCDs, but with an extended serial register to which a higher-than-usual voltage is applied. Secondary electrons are produced as the photon-generated electrons are clocked through it, resulting in a signal amplification which dwarfs the read-out noise, rendering it negligible.

EMCCDs have generated a lot of interest in the high spatial-resolution community, but have received much less attention for other astronomical applications. To address this problem, a consortium from the Universities of Sheffield, Warwick, the UK Astronomy Technology Centre and ESO, were awarded funding under OPTICON Joint Research Activity 3: *Fast read-out, high-performance optical detectors* to investigate the use of EMCCDs for high-speed spectroscopy. The resulting camera that has been developed is called *ULTRASPEC*, since it is essentially a spectroscopic version of ULTRACAM.

At the heart of ULTRASPEC is an EMCCD – we chose to use an E2V CCD201-20 detector, which has an imaging area of 1024 × 1024 pixels (each of 13 microns). The CCD201 is also a frame-transfer device, thereby offering high frame rates (up to hundreds of Hertz) with negligible dead time, as well as essentially zero read-out noise. The chip is mounted in a standard (old-style) ESO cryostat, cooled by liquid nitrogen and temperature-regulated by a Lakeshore controller (see Figure 1a). The chip read-out is controlled by a San Diego State University (SDSU) Generation III CCD controller, which incorporates a custom-made, high-voltage clock board to power the serial gain register (shown in Figure 1b). The SDSU controller is hosted by a rack-mounted dual-processor PC running Linux patched with Real Time Application Interface (RTAI) extensions. The use of RTAI allows one processor to be strictly controlled so as to obtain accurate timestamps from the GPS antenna located outside the dome and connected to the PC via a serial port. The data acquisition, instrument control and user interfaces are all virtually identical to the tried and tested hardware/software used in ULTRACAM.

Building a new spectrograph to test ULTRASPEC would have been prohibitively expensive and time consuming, and is unnecessary as so many excellent spectrographs with external foci able to accept visiting cryostats already exist. We identified the EFOSC2 spectrograph on the ESO 3.6-m telescope as ideal for our purposes, and the Director of the La Silla Paranal Observatory awarded us four nights of technical time in December 2006 to commission and test ULTRASPEC on the sky.

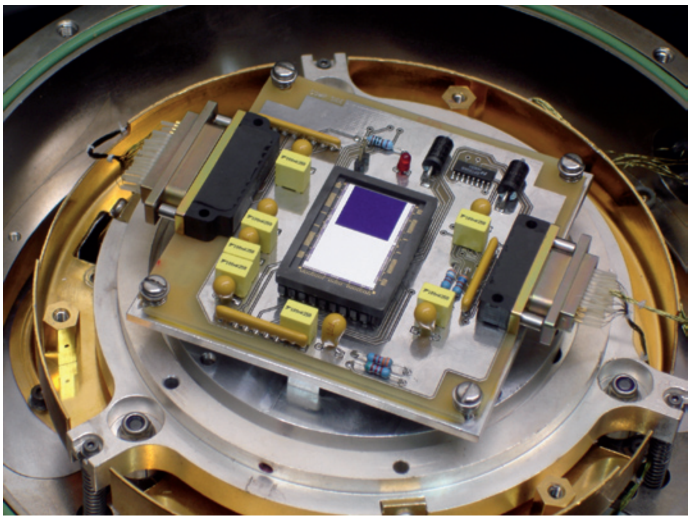

Figure 1a (left): The frame-transfer EMCCD chip mounted in the ESO cryostat.

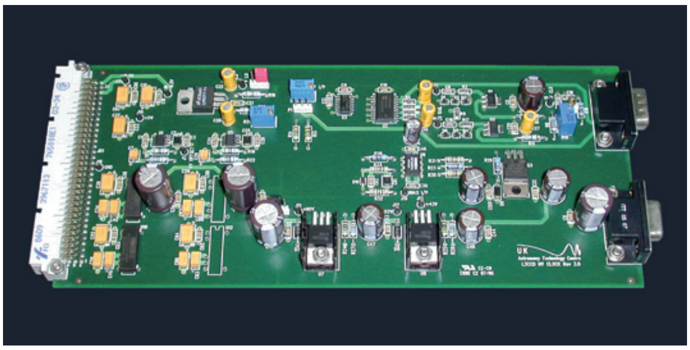

Figure 1b (above): The third and final version of the high-voltage clock board that was developed for the SDSU controller.

Figure 2a: View inside the Cassegrain cage of the ESO 3.6-m telescope, showing ULTRASPEC mounted on EFOSC2. The gold-coloured cryostat containing the EMCCD is visible at the bottom of EFOSC2. Close to this is the SDSU controller, mounted at the bottom of the red frame. The ULTRASPEC electronics rack containing the Lakeshore and PC is the unit on the left with a square black sticker on its door.

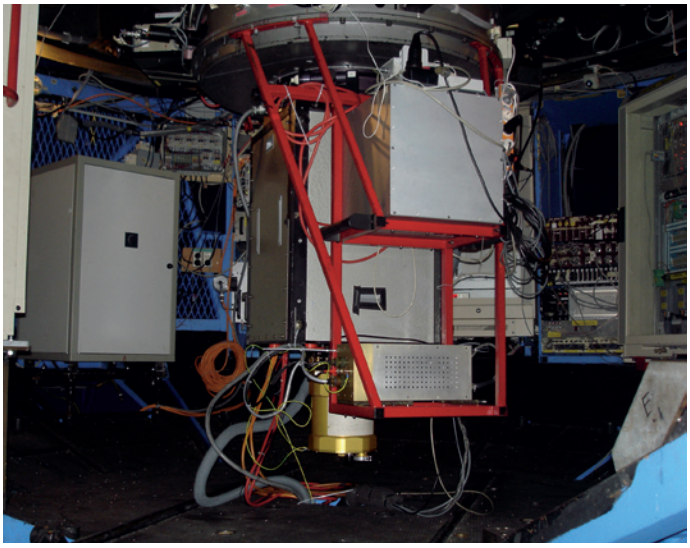

Figure 2b: The ULTRASPEC commissioning team. From left to right: Emilio Barrios (ESO), Naidu Bezawada (UKATC), Kieran O'Brien (ESO, standing), Vik Dhillon (Sheffield), Chris Copperwheat (Warwick), Tom Marsh (Warwick), Andy Vick (UKATC, standing).

The ULTRASPEC commissioning run was a great success. Installation, integration and alignment proceeded without problems, no telescope time was lost due to technical problems with ULTRASPEC, and the characterisation of the EMCCD chip was completed with a spectrograph on the sky. This latter task was the main aim of the run, and the main deliverable of our OPTICON-funded project, and was achieved by observing a series of standard stars ranging from magnitude 13 to 19 with different avalanche gains and exposure times (from hundredths of a second to hundreds of seconds). As an added bonus, we were also able to observe some demonstration science objects, which will serve as useful examples to the community of the power of EMCCDs for astronomical spectroscopy (see Figure 3). The results, which show that EMCCDs are likely to revolutionise certain types of (i.e. read-out-noise-limited) astronomical spectroscopy, will shortly be submitted for publication in a refereed journal.

With ULTRASPEC successfully commissioned, we are now keen to start using it to do science and are planning a science run on the ESO 3.6-m during Periods 80/81. There is little additional work to be done on ULTRASPEC in preparation for this proposed run, although we would like to purchase new VPH-based grisms for EFOSC2, providing higher resolutions and better-matched central wavelengths for ULTRASPEC's smaller CCD. In the longer term, we are also investigating the possibility of procuring a larger-format, multi-output EMCCD designed specifically for astronomical spectroscopy and using this in combination with the new Generation IV SDSU controller.

Any readers interested in using ULTRASPEC on a shared-risks, collaborative basis during Periods 80/81 are encouraged to contact Vik Dhillon (*vik.dhillon@sheffield.ac.uk*) or Tom Marsh (*t.marsh@warwick.ac.uk*). Users of SDSU controllers who are interested in adopting our high-voltage clock-driver board to control EMCCDs should contact Derek Ives (*dji@roe.ac.uk*).

Acknowledgements

This project would not have been possible without the support of the past and present Director of the La Silla Paranal Observatory – Jason Spyromilio and Andreas Kaufer – who authorised the use of technical time for this project and gave us unfettered access to an ESO cryostat and the EFOSC2 spectrograph. We are also indebted to Peter Sinclaire, Emilio Barrios and the other members of ESO staff on La Silla who provided expert assistance prior to and during the commissioning run.

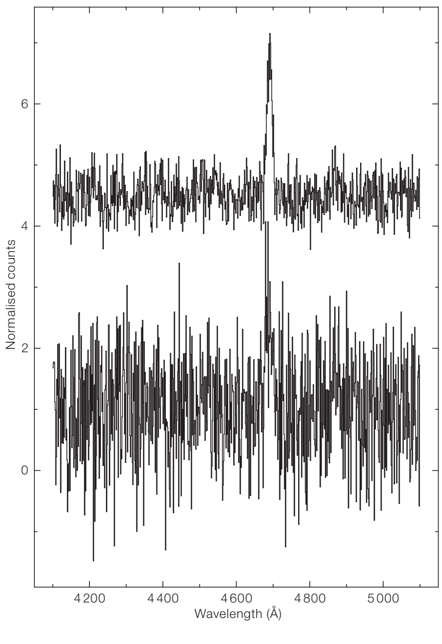

Figure 3: ULTRASPEC spectra of the AM CVn-star ES Cet, a binary of magnitude V ~ 17 consisting of two helium-rich white dwarfs in a very close 10-minute orbit. One of the white dwarfs is filling its Roche lobe and transferring material to its companion, producing the strong He II emission at 4686 Ångstroms visible in its spectrum. Top: A 10-second spectrum using the avalanche output of ULTRASPEC. Bottom: A 10-second spectrum taken using the normal output of ULTRASPEC. The latter is identical to what would be obtained using a conventional CCD. The gain in signal-to-noise is approximately a factor of three. Given that these are read-out-noise-limited observations, using an EMCCD on the ESO 3.6-m is therefore equivalent to using a conventional CCD on a 6.3-m telescope! The gain is even greater if the negligible dead time of the frame-transfer EMCCD (~ 10 milliseconds) compared to a conventional CCD (~ 10 seconds) is also taken into account.

Region of the Large Magellanic Cloud centred on SN 1987A (from ESO PR 50/06).