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ULTRACAM – an ultra-fast, triple-beam CCD camera

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Abstract. ULTRACAM is an ultra-fast, triple-beam CCD camera which has been designed to study one of the few remaining unexplored regions of observational parameter space – high temporal resolution. The camera will see first light in Spring 2002, at a total cost of £300 k, and will be used on 2-m, 4-m and 8-m class telescopes to study astrophysics on the fastest timescales.

1. Science

The fastest timescale variations likely to be observed in an astrophysical environment are milliseconds, corresponding to the innermost orbits around neutron stars and black holes. Variations of faint sources on timescales longer than a few seconds have already been explored by conventional CCD instruments. ULTRACAM will explore the region of observational parameter space which lies between these two extremes, namely photometry of faint objects on timescales of seconds to milliseconds. The resulting scientific applications will include the study of pulsars, occultations, XRBs (e.g. searching for the optical analogue of the kilohertz QPOs), speckle imaging, precise timing studies (e.g. measuring eclipses), echo mapping, eclipse mapping of CVs, asteroseismology, and flickering and oscillations in CV accretion discs.

The five essential requirements for such work are: 1. The capability of taking short exposures (from milliseconds to seconds) with essentially no dead-time between exposures; 2. Multi-channels (3 or more) covering a wide wavelength range (u' to z') in order to distinguish a blackbody spectrum from a stellar spectrum; 3. Simultaneous measurement of the different wavelength bands to avoid problems due to stochastic variations; 4. Imaging capability in order to simultaneously measure target, sky and comparison stars and to avoid the need for fixed apertures; 5. High efficiency and the capability of being mounted on various large aperture telescopes. These five requirements result in the instrument design presented here.

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2. Design

Optics. Light from the telescope is first collimated and then split into 3 bandpasses (u', g' and one of r', $i' or z'$) using dichroic beamsplitters and SDSS filters. The light from each filter is then re-imaged onto one of 3 CCDs at a plate scale of 0.3 arcseconds/pixel, giving a field of view of 5 arcminutes. This design ensures that: 1. There is an 80% probability of finding an R=12 magnitude comparison star in the field; 2. There is no ghosting due to the dichroics; 3. Only the collimator needs to be changed to mount ULTRACAM on a different telescope.

Mechanics. The opto-mechanical chassis is a double-octopod constructed of aluminium plates and carbon fibre struts, giving a stiff, compact (75cm long), lightweight (75 kg) structure which is relatively insensitive to temperature variations. These characteristics make ULTRACAM highly portable and mountable on both small and large aperture telescopes.

Detectors. ULTRACAM will use 3 Marconi (formerly EEV) 47-20 AIMO, back-thinned, AR-coated CCDs. These will be Grade 0 devices (i.e. of the highest cosmetic quality) and contain 1024x1024 image pixels, each of 13 microns, with 1024x1024 masked pixels (i.e. they are frame-transfer devices). The chips exhibit exceptionally high QE (up to 97%) and low noise (3 e^-/pixel readout noise and < 0.1 e^-/pixel/s dark current, achieved by cooling to 233 K using a 3-stage Peltier stack and water cooling).

Data acquisition and reduction. Data from the 3 CCDs is first read by an SDSU controller and then passed to a dual-processor PC running RTLinux. Each exposure is time-stamped by a GPS receiver to an accuracy of 0.01 milliseconds and then written to a RAID array and archived to tape. Pipeline data reduction software then fully reduces each data frame. Such a data acquisition and reduction system will enable us to observe for a whole night at the highest data rates (3.6 Mbytes/s) without stopping, building up light curves in real time.

3. Performance

Frame transfer chips allow a completed exposure to be rapidly shifted from the imaging area to the masked area and then read out whilst the next exposure is in progress. This, in conjunction with the high-speed data acquisition system described above, results in a full-frame readout time of 5 milliseconds (as long as the exposure time is > 2 s). By using small windows and stacking the windows in the masked area (a procedure known as 'drift mode'), it is possible to obtain dead-times of 0.05 milliseconds (as long as the exposure time is > 2 milliseconds), thereby meeting our requirement of millisecond exposure times with negligible dead time.

The optics and coatings in ULTRACAM have been designed with throughput as the highest priority. This, in conjunction with the exceptional QE performance of the CCDs, means that we expect to detect objects as faint as $\sim$ 17th magnitude at a signal-to-noise ratio of 3 in a 1 millisecond exposure on an 8-m class telescope.

For more information on ULTRACAM, please consult the instrument's web-site at http://www.shef.ac.uk/~phys/people/vdhillon/ultracam.