ULTRACAM – a high-speed, triple-beam CCD camera

Final report on PPARC grant PPA/G/S/1998/00534

Vik Dhillon & Tom Marsh, 25 November 2002

1 Introduction

ULTRACAM is an ultra-fast, three-channel CCD camera designed to provide imaging photometry at high temporal resolutions. The instrument, which saw first light on the WHT on 16/05/2002 (over three months ahead of schedule and within budget), was funded in full (£292 034) by PPARC on 02/09/1999 and built by the Universities of Sheffield, Southampton and the UK Astronomy Technology Centre. The purpose of this document is to provide a final report on the research grant award.

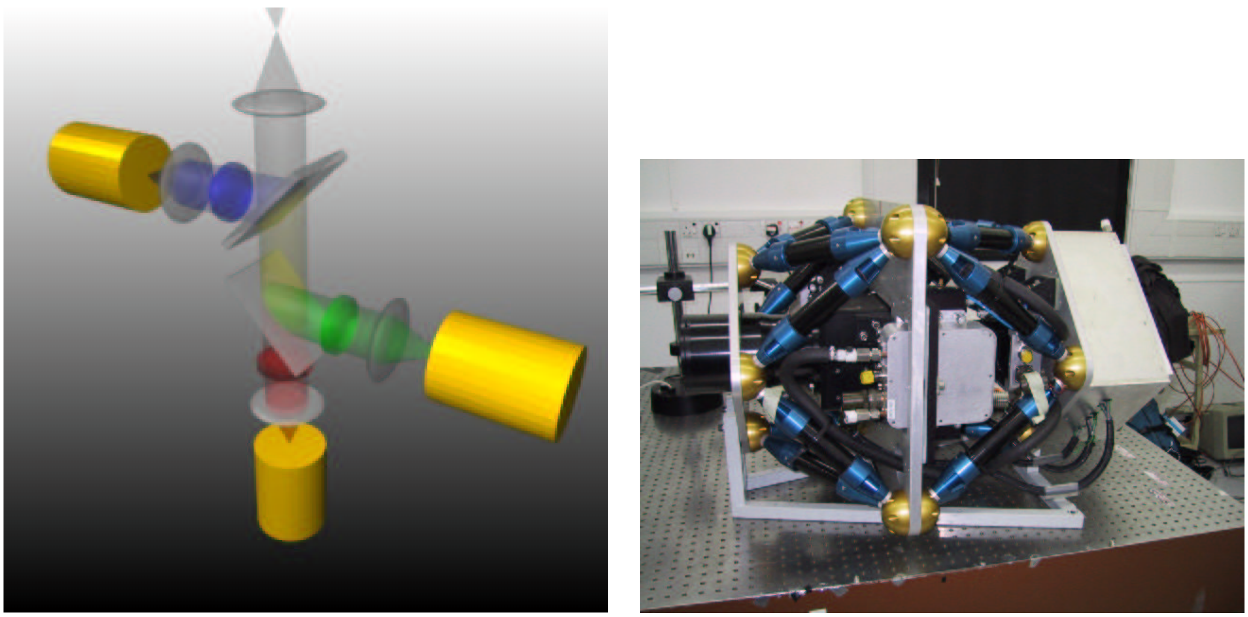

Figure 1: Left: Schematic showing the light path through ULTRACAM. Right: ULTRACAM in the test focal station at the WHT, just prior to mounting on the telescope.

2 Management structure and work packages

The ULTRACAM project was managed by the PI, Vik Dhillon, at the University of Sheffield. The PI was in overall control of the budget and the integration of the four ULTRACAM work packages: the mechanical structure (Sheffield), the optics design, procurement and alignment (Sheffield/UKATC), the pipeline data reduction system (Tom Marsh, Southampton) and the detector and data acquisition system (UKATC). The latter work package accounted for three-quarters of the total budget of the ULTRACAM project and had its own local project manager at the UKATC (David Lunney). Scientific issues, and in particular the impact of various design decisions on the performance of the instrument, were the responsibility of the ULTRACAM project scientists, who were jointly Vik Dhillon and Tom Marsh.

3 Timescales and milestones

The major milestones in the project are listed in chronological order below and serve a useful purpose in describing how the project proceeded from the initial design stages, through the construction phase to final commissioning on the telescope.

16 Jun 1999	Notified by PPARC that grant application successful.
26 Jul 1999	Meeting at CLRC to discuss contract for data acquisition system.
02 Sep 1999	Official start date of PPARC grant.
03 Sep 1999	Meeting at UKATC to discuss contract for data acquisition system and optical design.
14 Sep 1999	UKATC selected to receive contract for data acquisition system and optics.
12 Jan 2000	Functional and performance requirements document completed and sent to the UKATC for comment.
10 Mar 2000	First design meeting at the UKATC.
19 Jun 2000	Draft contract circulated by UKATC.
12 Jul 2000	Second design meeting at the UKATC.
23 Aug 2000	ULTRACAM contract with UKATC signed.
22 Sep 2000	SDSU controller and CCDs ordered.
01 Oct 2000	Mark Stevenson (Sheffield) joins project and begins mechanical design.
31 Oct 2000	Optical design completed.
01 Nov 2000	First of regular bi-weekly teleconferences held between UKATC and Sheffield.
21 Nov 2000	Meeting at UKATC to discuss tender document for optics and to finalise CCD head design.
08 Mar 2001	Order for optics sent to Specac.
15 Mar 2001	First light with the ULTRACAM CCDs in the laboratory.
23 May 2001	ULTRACAM Critical Design Review at the UKATC.
29 August 2001	ULTRACAM Mechanical Design Review at the UKATC.
28 February 2002	ULTRACAM optics delivered by Specac to Sheffield.
20 March 2002	Construction of ULTRACAM mechanical structure completed at Sheffield workshops.
25 March 2002	Alignment and integration of the optics, mechanical structure and CCD cameras at the UKATC.
23 April 2002	Pipeline data reduction system integration meeting at the UKATC.
03 May 2002	ULTRACAM shipped to La Palma.
16 May 2002	First light on the WHT.

The grant award was for the design, construction and commissioning of ULTRACAM, not for its scientific exploitation. Hence it can be seen that the project was completed over 3 months ahead of the schedule set in the original grant proposal. It can also be seen that proper project management procedures were followed throughout the course of the project, including the preparation of a detailed requirements document, the careful selection of contractor for the data acquisition system, and a series of design reviews (attended by both project personnel and external assessors).

4 Budget

PPARC awarded £292 034 for the design, construction and commissioning of ULTRACAM. This amount proved sufficient (exactly!) to complete the instrument to specification, without any sacrifice in performance. We did overspend in one area – our estimate of 0.27 staff years for the mechanical construction at the Sheffield workshops underestimated how much time was actually needed. Fortunately, this additional cost was absorbed by the Department of Physics and Astronomy at Sheffield (who have a number of technicians in the workshops on their payroll) and hence the project was completed within the PPARC-allocated budget.

A breakdown of expenditure on the grant is given below. Please note that the figures given below are only a guideline as to how the grant money was spent. Full and final details will be sent to PPARC in the FES.

staff	0.27 staff years of technician time in the Central Mechanical Workshops at Sheffield for the design and construction of the opto-mechanical chassis	5080.00
	0.09 staff years of Paul Kerry at Sheffield for system management of the ULTRACAM computers and peripherals	1693.00
	indirect cost on staff (46%)	3115.58
	sub-total	**9888.58**
equipment	manufacture, coating and assembly of the ULTRACAM optics by Specac	30 205.20
	1 set of SDSS filters (u'g'r'i'z') from Asahi	3293.98
	2 dichroic beamsplitters (substrates+coatings) from CVI Technical Optics	6308.58
	SCSI disk array containing 4x73 Gbyte drives from GND Distribution Ltd	2956.30
	data reduction PC, including Athlon XP1900+ (1.6 GHz) processor, 1.5 Gbytes DDR memory, 60 Gbyte IDE drive, 73 Gbyte SCSI disk, 18" LCD monitor, DVD drive, CDRW drive, aluminium case and 550W PSU	3300.00
	mechanical parts	939.24
	sub-total	**47 003.30**
exceptional items	contract with UKATC for three CCD cameras, data acquisition system and optical design	229 000.00
	sub-total	**229 000.00**
consumables	optics handling and cleaning equipment, tapes, cables/pipes	1862.93
	sub-total	**1862.93**
travel	travel & subsistence	4279.19
	sub-total	**4279.19**
	total	**292 034**

5 Commissioning

ULTRACAM saw first light on 16 May 2002 on the WHT on a commissioning night awarded to the project team by the ING board. The instrument performed to specification in every area (sensitivity, speed, flexure, image quality, alignment, noise levels). In fact, the commissioning night was so successful that for the last few hours of the night we undertook the science observations we had intended to perform in PATT-allocated time the following night. As well as working to specification, the instrument proved to be extremely reliable, with only 30 minutes lost to technical downtime during the recent 13-night observing run on the WHT in September 2002.

6 Telescope time

Following the commissioning night on 16 May 2002, we observed 4 nights of PATT-allocated time on 17–20 May 2002. One of the proposals (Marsh, W/02A/7) was the highest rated proposal allocated time on the WHT by PATT in semester 2002A. We were also highly successful in winning time in Semester 2002B, with a total of 13 nights allocated to the instrument between 9–21 September 2002 by PATT, CAT and the NL. Note that we currently make ULTRACAM available to anyone who

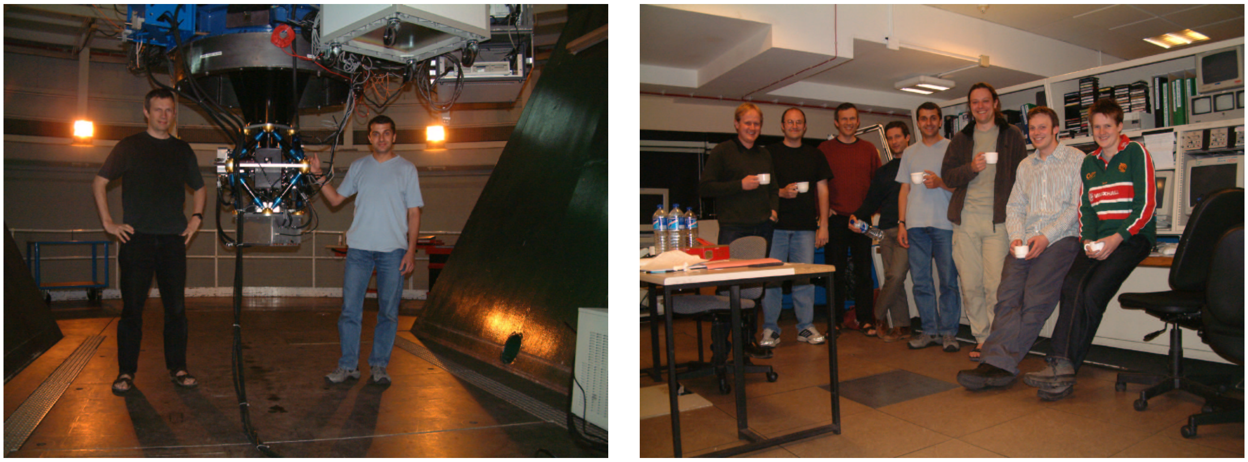

Figure 2: Left: ULTRACAM mounted on the Cassegrain focus of the WHT. Right: The ULTRACAM commissioning team (from left-to-right: Mark Stevenson (Sheffield), Paul Kerry (Sheffield), Tom Marsh (Southampton), Marco Azzaro (ING), Vik Dhillon (Sheffield), Andy Vick (UKATC), David Atkinson (UKATC), Carolyn Brinkworth (Southampton).

wishes to use it at the Universities of Sheffield and Southampton. In addition to this, we have been inundated with unsolicited requests to use the instrument from other members of the UK community (and a number of UK astronomers currently based abroad). We have agreed to all of these requests, which resulted in the list of proposals given below being awarded time in Semesters 2002A and 2002B.

PI	Co-I's	Nights	Project title
Jeffery (Armagh)	Dhillon, Marsh Heber, Falter (Nurnberg) Woolf, Ahmad (Armagh)	4B	Colorimetric mode identification in pulsating subdwarf B stars
O'Brien (Amsterdam)	Dhillon, Marsh van der Klis (Amsterdam) Klein-Wolt (Amsterdam) Still (NASA/GSFC)	3B	Optical analogues of X-ray timing phenomena in X-ray binaries using ULTRACAM and RXTE
Shahbaz (IAC)	Dhillon, Marsh Charles, Hynes (Soton) Haswell (OU) Casares, Zurita (IAC)	3G	High time-resolution optical studies of quiescent black-hole X-ray transients
Hulleman (Utrecht)	Dhillon, Marsh van Kerkwijk (Utrecht) Kulkarni (Caltech) Shearer, Golden (Galway)	3D	The nature of magnetars: ULTRACAM observations of the anomalous X-ray pulsar 4U 0142+61
Dhillon (Sheffield)	Marsh	1B	ULTRACAM commissioning
Marsh (Southampton)	Dhillon, Stevenson (Shef) Maxted (Keele) Brinkworth (Soton)	3B	Magnetic braking and solar cycles in detached binary stars
Dhillon (Sheffield)	Marsh Schwope (Postdam) Brinkworth (Soton) Stevenson (Shef)	1G	Coordinated optical and X-ray observations of the eclipsing polar HU Aqr

7 Science

The above table shows that ULTRACAM has been used to observe a diverse range of astrophysical targets at high temporal resolution, including pulsars, eclipsing binary stars, cataclysmic variables, black-hole X-ray binaries, neutron-star X-ray binaries and asteroseismology. Some of the initial results from these runs are presented in the accompanying figures.

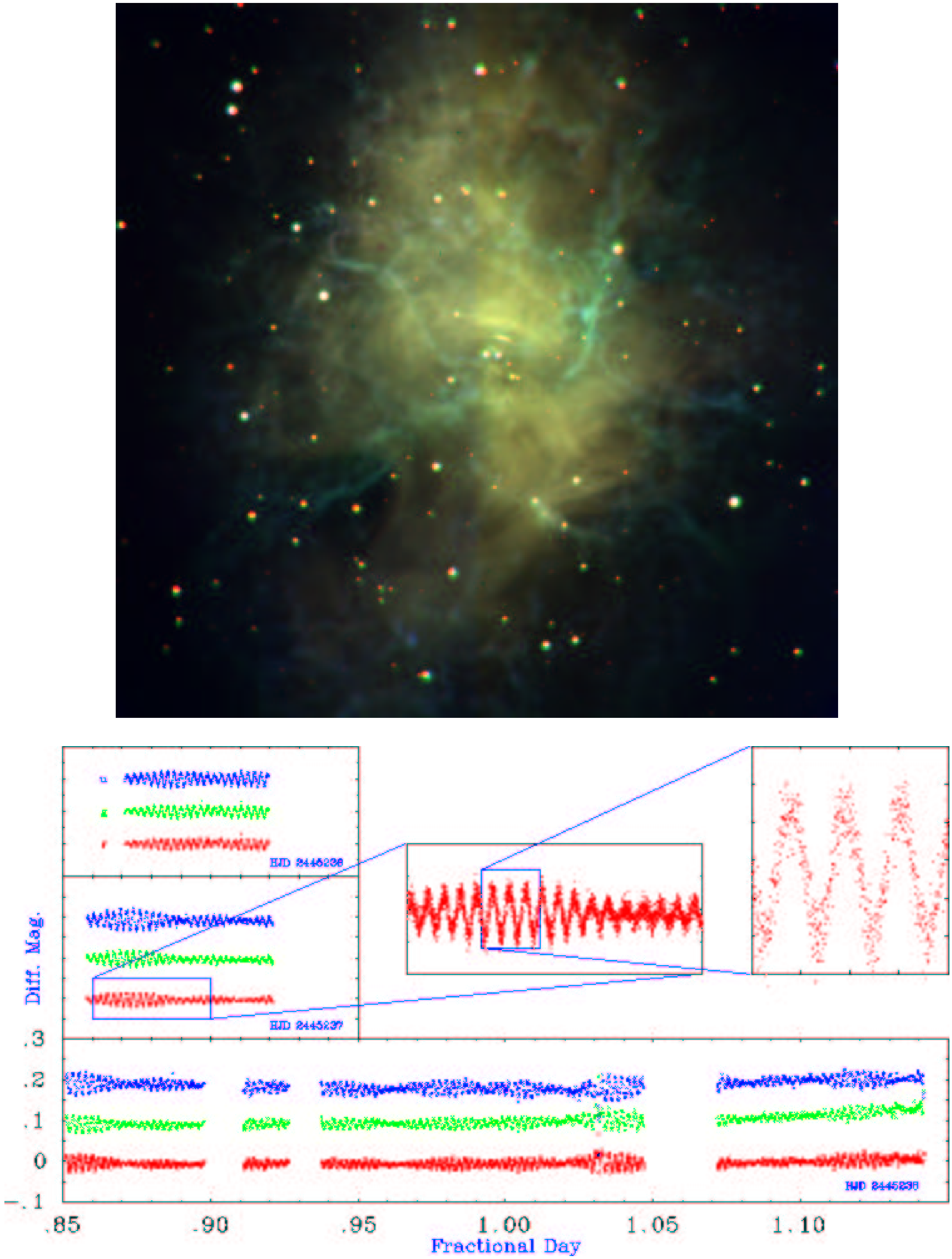

Figure 3: Top: Image of the Crab Nebula, obtained by combining the simultaneous u', g' and r' ULTRACAM images. Fast data on the crab pulsar at the centre of this image were obtained in order to calibrate the accuracy of the ULTRACAM GPS time-stamping. Bottom: Light curve of the pulsating sdB star KPD2109+4401 obtained by Simon Jeffery (Armagh) for use in his ULTRACAM asteroseismology project.

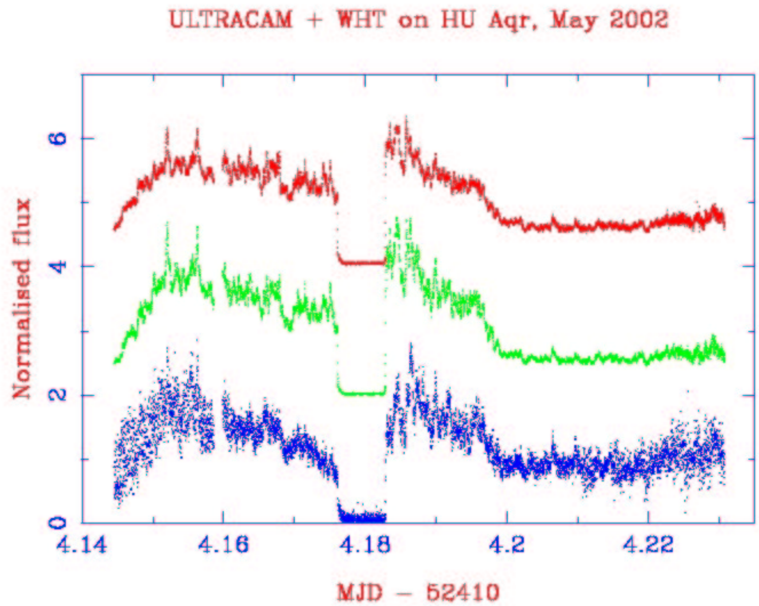

Figure 4: Light curve of the eclipsing polar HU Aqr, which consists of a white dwarf accreting material onto its magnetic poles from a red dwarf companion star. The light curve shows intense flickering from the accreting poles and the eclipse of the poles (the 2-3 second transition into eclipse).

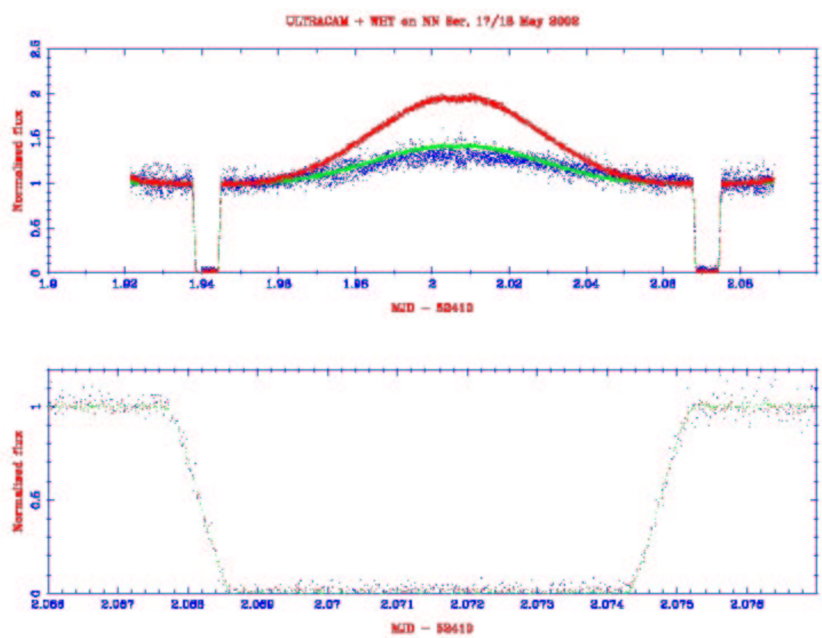

Figure 5: Light curve of the eclipsing white-dwarf/red-dwarf binary NN Ser. Each point on the graph represents a 2 second exposure. The upper panel shows the u', g' and r' flux versus time. The rise in the centre of the curve is due to a reflection effect, where the irradiated inner hemisphere of the cooler star comes into view. The lower panel is an expanded plot of the eclipse. The eclipse is due to the obscuration of the hot white dwarf by the cool red dwarf and will be used to measure the masses and radii of the two stars (using a full light curve fit) and the rate at which the orbital period of the binary is decreasing.

8 Future work

When we designed ULTRACAM, we were determined that the instrument would not follow the fate of many other private instruments and be used for only a handful of PATT-awarded nights each semester. We therefore entered negotiations with the National Observatory of Athens (NOA), who have contracted Zeiss to deliver a high quality 2.3-m telescope ("Aristarchos") at a good site in Greece – the 2340-m Mount Chelmos in the Peloponnese. The result of these negotiations is a Memorandum of Understanding between the NOA, Sheffield and Southampton, which states that ULTRACAM will be permanently mounted on one of the side ports of Aristarchos whenever we do not need to use it on a larger telescope (e.g. the WHT or VLT). In return, we will receive 10% of the observing time on Aristarchos, which will facilitate long-term monitoring projects of rapidly varying objects, something which is currently not possible to accomplish through PATT. We expect ULTRACAM to see first light on Aristarchos towards the end of 2003. Immediately after this, we hope to use ULTRACAM at the Visitor Focus of the VLT for the first time – we are currently in negotiations with ESO over this matter.

9 Papers

As the first science runs with ULTRACAM took place as recently as May and September 2002, all of the science papers which will result from these runs are still in preparation. There have, however, been a number of papers on the instrument design, which are listed below.

1. Dhillon, Marsh, 2001, ULTRACAM - studying astrophysics on the fastest timescales, New Astronomy Reviews, 45, 91

2. Dhillon et al, 2002, ULTRACAM – an ultra-fast, triple-beam CCD camera, ASP Conference Series 261: The Physics of Cataclysmic Variables and Related Objects, 672

3. Beard et al, 2002, The ULTRACAM camera control and data acquisition system, in Advanced Telescope and Instrumentation Control Software II, Lewis H, SPIE 4848, Astronomical Telescopes and Instrumentation, Waikoloa 2002

4. Tierney, Beard, 2002, The design of an object-orientated, distributable camera control system for the ULTRACAM project, in Astronomy Data Analysis and Software Systems XI, ASP, San Francisco

5. Dhillon et al, 2002, ULTRACAM successfully commissioning on the WHT, ING bulletin, December 2002

10 Summary

1. The ULTRACAM project has been completed within budget and ahead of schedule.

2. The instrument has performed to specification, making ULTRACAM one of the most powerful tools in the world for the study of fast astrophysics.

3. The instrument is in great demand by UK astronomers, resulting in 17 nights of WHT time in the last 2 semesters (including the top-ranked WHT proposal in semester 2002A).

4. From 2004 onwards, whenever it is not required for observations on the WHT or VLT, ULTRACAM will be permanently mounted on the Aristarchos Telescope in Greece. UK astronomers will have 10% of the time on this telescope as a result.

For more detailed information on ULTRACAM please consult the instrument web pages at http://www.shef.ac.uk/~phys/people/vdhillon/ultracam.