European Organisation for Astronomical Research in the Southern Hemisphere

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **80A**

Important Notice:

1. Title Category: **D–7**

The rotation rates of white dwarfs in binaries

2. Abstract

The rotation of white dwarfs in binary stars may affect whether they undergo accretion-induced collapse or thermonuclear explosions as Type Ia SNe. It can also have a profound impact upon the survival of the binary systems through merger events. The limited observational constraints upon this important parameter suggest rotation rates well below what would be expected in the case of accreting systems, suggestive of some mechansim that brakes the white dwarfs. Unfortunately the measurements, based upon photospheric lines from the white dwarfs in ultraviolet spectra from HST, have sometimes been contradictory and a worry is that circumstellar material may be obscuring the white dwarfs. In this proposal we request time to test a completely independent method based upon radial velocity distortions expected during eclipse. To carry this out we will take high-speed spectroscopy with a recently commissioned camera "ULTRASPEC" which employs a photon-counting CCD.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	80	Special3.6	5n	feb	g	$\leq 1.2''$	THN	v

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:		
b) still required to complete this project:		

5. Special remarks:

This is a proposal to use an L3CCD called "ULTRASPEC" which was commissioned in December on EFOSC. L3CCD employs avalanche multiplication gain to eliminate readout noise and are thus good for high-speed readout-limited spectroscopy. See section 15 for further details.

6. Principal Investigator: T. Marsh (University of Warwick, UK, t.r.marsh@warwick.ac.uk)

CoI(s): C. Copperwheat (University of Warwick, UK), S. Littlefair (University of Sheffield, UK), V. Dhillon (University of Sheffield, UK), C. Watson (University of Sheffield, UK)

7. Is this proposal linked to a PhD thesis preparation? State role of PhD student in this project

8. Description of the proposed programme

A) Scientific Rationale:

The rotation speeds of white dwarfs in close binary stars can tell us about past episodes of accretion, and affect the entire stability and future evolution of the binaries themselves. Examples are (i) the effect of white dwarf rotation upon the accretion-induced collapse events (Dessart et al 2006) and even whether a collapse or a Type Ia explosion occurs (Yoon & Langer 2006), (ii) the coupling of white dwarf spin to the binary orbit in double white dwarf systems which can alter the survival rate of double white dwarf mergers by as much as 100 times (Marsh et al 2004), and (iii) the observation of rapid rotation of the white dwarf in the detached white dwarf/M dwarf binary QS Vir which suggests, very surprisingly, that it might once have been a cataclysmic variable star (CV) (O'Donoghue et al 2003). The question in the third example is how could the system once have transferred mass and yet be detached now given that angular momentum loss always drives systems towards tighter orbits with time.

The low moments of inertia of white dwarfs and the fact that they shrink in response to an increase of mass imply that they need only accrete $\sim 0.1\,M_\odot$ to be spun up to 50% of their break-up rate. It is surprising then that what evidence we do have from accreting binary stars suggests that the white dwarfs rotate well below their breakup speeds. The breakup equatorial speeds of white dwarfs are of order 3000 to 8000 km s^{-1}, depending on their mass, but values measured from the ultraviolet spectra of CVs are typically of order 400 km s^{-1}, with the best-determined case, U Geminorum, having a value $v \sin i < 100$ km s^{-1} (Sion et al. 1994). Similarly, some helium accreting white dwarfs show narrow emission lines which are thought to come from the white dwarfs and which again indicate rotation speeds below 100 km s^{-1}(Marsh 1999; Ruiz et al 2001). This suggests that there may be some way to brake the white dwarf rotation. Nova explosions have been suggested (Livio & Pringle 1998) but this explanation fails to explain the helium accretors for which nova explosions are few and far between allowing the accretion of considerable amounts of mass compared to their hydrogen-dominated counterparts; an alternative recently suggested in the context of double white dwarf mergers is tidally-driven resonance between the orbit and oscillation modes of the white dwarfs (Racine et al, 2006). This mechanism can lock the white dwarf to the orbit, and therefore stabilise double white dwarf binaries during mergers, which is significant for potential sources for the gravitational wave observatory LISA. It remains to be seen whether this can work at long orbital periods, but whatever the cause, the low rotation speeds measured suggest the action of a dissipative mechanism that could have a significant effect upon white dwarf mergers and Type Ia models, as outlined above.

The number of systems with measured rotation velocities is small – a generous list runs to about 10 systems. Even then, the values are open to doubt: for instance measurements of $v \sin i$ of the white dwarf in the CV WZ Sge have varied from 1200 km s^{-1} (Cheng et al 1997) to more recent values of ~ 300 km s^{-1} (Long et al 2003). It is not possible that the white dwarf rotation rate can truly have slowed by this amount, which casts considerable doubt upon the validity of the measurements of rotational broadening from the UV metal lines, presumed to be from the white dwarf photospheres. Possible problems are that abundance and rotation rate are rather degenerate and that some absorption could be from the accretion disk, not the white dwarf. In the case of the helium accretors the interpretation of the narrow emission lines remains uncertain; they may not reflect the rotation of the white dwarfs at all.

What is urgently needed is an independent measurement of the rotation rates of the white dwarfs in binary stars to establish once and for all that they are relatively slowly rotating, or not, as the case may be. Here we aim to observe the change of apparent radial velocity that occurs as white dwarfs are occulted in eclipsing systems. For instance consider a point during eclipse ingress when half of the white dwarf is obscured. If the white dwarf is spinning then the visible half of the white dwarf will be on average red-shifted (Figs 1 and 2). This effect is a well known one in binary stars and sometimes termed the Rossiter effect (Rossiter 1924). As Figs 1 and 2 show, measurements of the radial velocity of the white dwarfs during eclipses have the potential to provide estimates of the rotations speeds which are completely independent of the UV measurements. Accomplishing this is the aim of our proposal. We have selected two accreting targets, Z Cha and OY Car, and the detached system QS Vir referred to above, where our aim is the independent verification of a high rotation rate suggestive of a past episode of accretion.

References:

Cheng, F.-H., et al 1997, ApJ, 484, 149
Dessart, L., et al., 2006, ApJ, 644, 1063
Liovio, M., Pringle, J., 1998, ApJ, 505, 339
Long, K., et al, 2003, ApJ, 591, 1172
Marsh, T, 1999, MNRAS, 304, 443
Marsh, T., Nelemans, G., Steeghs, D., 2004, MNRAS, 350, 113
O'Donoghue, D., et al, 2003, MNRAS, 345, 506
Racine, E., et al 2006, astro-ph/0610692
Rossiter, R.A., 1924, ApJ, 60, 15

8. Description of the proposed programme (continued)

Ruiz, M.-T., et al 2001, ApJ, 552, 679
Sion, E.M. et al, 1994, ApJ, 430, 53
Yoon, S.-C., Langer, N., 2005,A&A, 435, 967

B) Immediate Objective:

The observations are in principle straightforward, but very demanding in practice because of the short timescales involved. Eclipses of the white dwarfs in our targets typically last no more than 10 minutes, but more stringently still, the ingress and egress transitions last of order 40 seconds. These must be resolved which requires taking spectra every few seconds. There is then a simple reason why these observations have never been undertaken before: readout noise. Bearing in mind that the systems become faint during eclipse, one is simply buried under detector noise. This changes with the advent of "Low Light Level" or "electron multiplying" CCDs. These are normal CCDs with additional readout stages inserted after the serial readout but before the charge is amplified. The additional readout stages are clocked with larger than normal voltages leading to a finite chance that one electron becomes two, leading in the end to a large avalanche multiplication which can be a factor of 1000 or more. This means that the standard readout noise added by the amplifier is much less that the charge produced by a single photon. In effect the readout noise is made negligible and so these CCDs can act as photon counters, whilst retaining the usual CCD advantages of high quantum efficiency and geometric stability.

Using hardware from the ULTRACAM high-speed camera, we have recently (Dec 2006) commissioned an L3CCD camera ("ULTRASPEC") on EFOSC2 on the 3.6 m at La Silla – section 15 contains further details. We propose now to apply this to the problem of white dwarf rotation. This CCD is easily capable of the necessary time resolution; the question then becomes how many eclipses need to be measured. We estimate the order of magnitude by considering the velocity accuracy needed when the white dwarf is half-eclipsed. At this time, the velocity shift will be $\sim 40\%$ of $v \sin i$, i.e. 160 km s^{-1}for the typical values estimated from UV data. The uncertainty in velocity is $\sigma_v = 1/\sqrt{\sum_i (df_i/dv)^2/\sigma_i^2}$ (Cramer-Rao limit), where $f_i(v)$ is the predicted flux as a function of velocity v in pixel i and σ_i^2 is the variance. For $f_i(v)$ we used a model of Hβ for a white dwarf of $T_{\rm eff} = 15000$, $\log g = 7.5$ diluted by a factor of 2 to allow for accretion light (Fig. 3). To account for the emission lines from accretion, we only evaluate the sum > 2200 km s^{-1} from line centre; the broad absorption wings of white dwarfs extend far beyond this range. We take the total exposure time per eclipse to be the sum of the ingress and egress transition times, i.e. ~ 60 sec, although in practice we would take many shorter exposures and be looking for a variation of velocity with time (Fig. 2). Assuming a mean brightness of $V = 17$, representative of the time when half the white dwarf is eclipsed, we used the EFOSC ETC to calculate the count rate in the continuum at Hβ (using grsim 6) and then our model to calculate df_i/dv and σ_i^2 and hence σ_v. We estimate $\sigma_v \sim 200$ km s^{-1} for one eclipse. We aim to cover 15 to 20 eclipses in our accreting targets Z Cha and OY Car which will be enough to allow us to detect the 160 km s^{-1} shift corresponding to $v \sin i = 400$ km s^{-1}at the 3σ level. Our observations will easily establish whether the white dwarfs are rotating anywhere near breakup. We will also look at the non-accreting system QS Vir, which is brighter and for which we can use more of the line profile. We estimate an uncertainty of order 30 km s^{-1} per eclipse on this target which will provide us with a good test of the limits of the method. We aim to cover 5 eclipses of this system. We will use grism 3, which gives coverage from 3760 to 5150Å over ULTRASPEC's 1024 pixels, giving coverage of the higher Balmer lines where the white dwarf is most significant.

In another application (PI: Watson) we aim to examine the disc lines with observations of Hα, with two targets in common. The aims of the two proposals are essentially different: in this case we are interested in the white dwarfs and therefore require low resolution spectra in the blue, while for disc lines one needs higher spectral resolution and to observe Hα to which the white dwarf makes little contribution.

C) Telescope Justification: We have only commissioned ULTRASPEC on the 3.6 m and EFOSC2, and it is thus our only choice. While we could do with more collecting area, in this case we will compensate using multiple eclipses.

D) Observing Mode Justification (visitor or service): ULTRASPEC is a visiting instrument and must be operated in visitor mode.

E) Strategy for Data Reduction and Analysis: We have written a special purpose reduction suite for ULTRASPEC. The aim will be to extract spectra around eclipses, then co-add them in phase before measuring the radial velocity of the white dwarf. Copperwheat will work full time on this project.

8. Attachments (Figures)

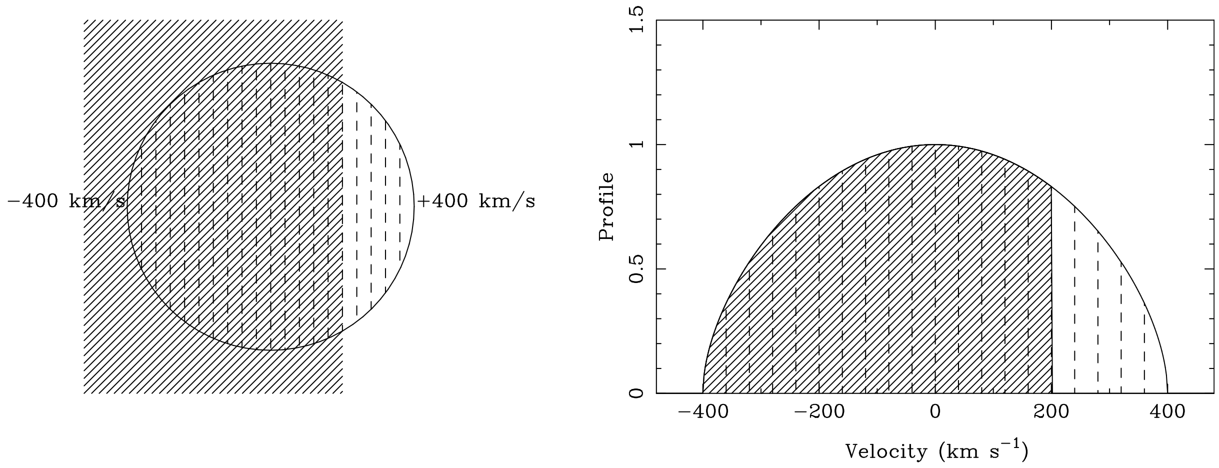

Fig. 1: On the left is a schematic view of a white dwarf 75% into eclipse ingress with the occulted region (shaded) moving from left to right. Vertical dashed lines are lines of equal radial velocity. The $v \sin i$ of the white dwarf is taken to be 400 km s^{-1}. At the phase shown, one only sees the receding hemisphere. The equivalent limb darkened profile is shown on the right. The unocculted region shows a mean shift of order 250 km s^{-1}. It is this shift, which is a measure of $v \sin i$, that we wish to detect.

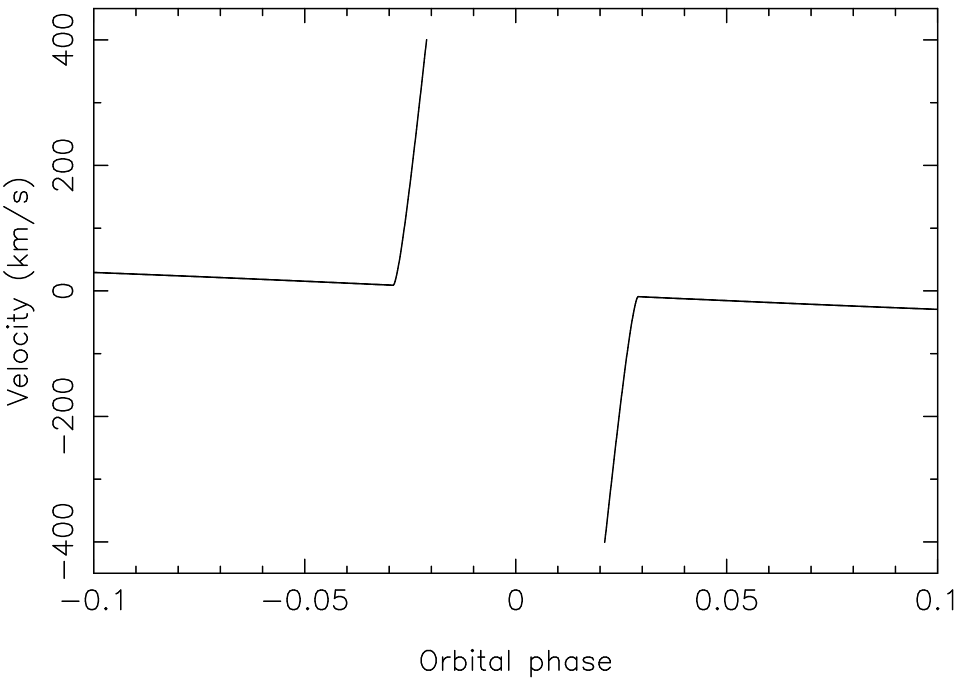

Fig. 2: the radial velocity offset from the Rossiter effect on a white dwarf with an equatorial rotation velocity of $v \sin i = 400$ km s^{-1} seen on top of the relatively slowly varying projected orbital speed of the white dwarf. Although the effect is large, it is also short-lived given orbital periods ~ 100 mins. (The x-axis is scaled in terms of the orbital period.) One should also bear in mind that the largest excursions are based on only small visible portions of the white dwarf and are thus difficult to observe because of limited signal. The central gap covers the period when the white dwarf is totally eclipsed.

8. Attachments (Figures)

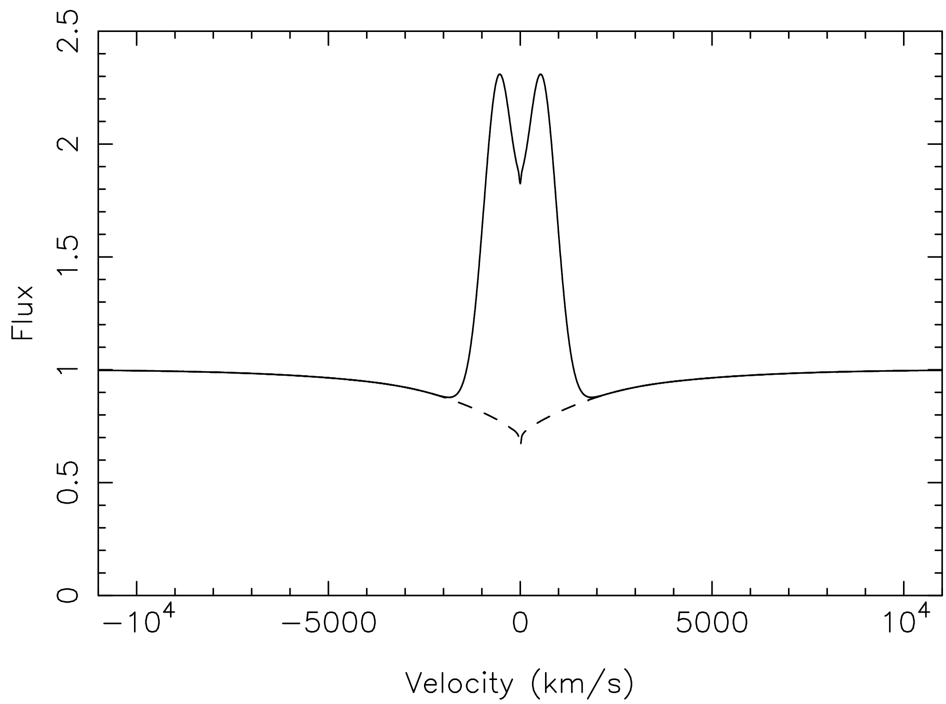

Fig. 3: in accreting systems, the double-peaked emission lines from the disc mean that we will have to measure the radial velocity of the white dwarf from the Stark-broadened absorption wings. This is also true for our detached target because of narrow line emission from its M companion, but the effect is considerably smaller. The effect of this is allowed for in our computation of the Cramer-Rao bound on the radial velocity uncertainty.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: Our targets reach $V = 17 - 18$ in eclipse and thus we request grey time.

Time Justification: (including seeing overhead) As outlined in section 8B, we aim to cover 20 eclipses of our faintest target, OY Car, which has a period of 1.5 hours. This therefore requires 30 hours, i.e. a little less than 4 nights. We also wish to cover ~ 15 eclipses of the other accretor Z Cha, and 5 of the detached system QS Vir. We will endevour as much as possible to interleave the eclipses, but given that eclipses often coincide in phase, we will need some extra time and therefore request a total of 5 nights.

Calibration Request: Standard Calibration

10. Report on the use of ESO facilities during the last 2 years

076.D-0228, ULTRACAM/VLT data on the 5 minute binary RXJ0806+1527. Nice data, definitely establishing the relatve optical and X-ray phases. Paper: Barros, Marsh et al, 2007, MNRAS, 374, 1334.
079.D-0518, ULTRACAM/VLT run, to be observed June 2007.

11. Applicant's publications related to the subject of this application during the last 2 years

Littlefair S. et al., 2006, Science, 314, 1578, *A Brown Dwarf Mass Donor in an Accreting Binary*

Southworth J. et al 2006, MNRAS, 373, 687, *VLT/FORS spectroscopy of faint cataclysmic variables discovered by the Sloan Digital Sky Survey*

Steeghs D. et al, 2006, ApJ, 649, 382, *GEMINI Spectroscopy of the Ultracompact Binary Candidate V407 Vulpeculae*

Unda-Sanzana E. et al, 2006, MNRAS, 369, 805, *Optical spectroscopy of the dwarf nova U Geminorum*

Aerts C. et al, 2006, MNRAS, 367, 1317, *High-speed colourimetry of the subdwarf B star SDSSJ171722.08+58055.8 with ULTRACAM*

Brinkworth C. et al, 2006, MNRAS, 365, 287, *Detection of a period decrease in NN Ser with ULTRACAM: evidence for strong magnetic braking or an unseen companion*

Morales-Rueda L. et al, 2006, BaltA, 15, 187, *Subdwarf B Binaries in the Edinburgh-Cape Survey*

Jeffery S et al 2005, MNRAS, 362, 66, *Multicolour high-speed photometry of the subdwarf B star PG 0014+067 with ULTRACAM*

Nelemans G. et al 2005, A&A, 440 1087, *Binaries discovered by the SPY project. IV. Five single-lined DA double white dwarfs*

Morales-Rueda L et al, 2005, MNRAS, 359, 648, *Six detached white-dwarf close binaries*

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	Z Cha	08 07 28.2	-76 32 01	12	15.3		$P_{\rm orb} = 1.8\,$h	
A	OY Car	10 06 22	-70 14 05	18	16.7		$P_{\rm orb} = 1.5\,$h	
A	QS Vir	13 49 52.0	-13 13 38	10	14.3		$P_{\rm orb} = 3.6\,$h	

Target Notes: The targets have been selected for their brightness and high radial velocity semi-amplitudes K (listed above) because this gives the highest sensitivity to eccentricity.

12b. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If yes, explain why the need for new data.

The observations we propose are unique and have not been attempted before.

13. Scheduling requirements

3. Unsuitable period(s) of time

Run	from	to	reason
A	01-oct-2007	10-jan-2008	RAs of targets

14. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list

15. Visitor instrument

Description of the instrument and of its operation:

ULTRASPEC is essentially a spectroscopic version of the high-speed, triple-beam imaging photometer ULTRACAM. In combination with the EFOSC2 spectrograph on the ESO 3.6m telescope, ULTRASPEC provides high speed (up to $\sim$100 Hz) spectroscopy with zero readout noise. It achieves this by using an E2V CCD201 detector mounted in a standard ESO cryostat and the ULTRACAM data acquisition hardware/software. The CCD201 is a so-called *electron-multiplying* CCD (or EMCCD). This is a frame-transfer device (hence providing high speed and negligible dead-time) 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 readout noise, rendering it negligible. In all other respects, the CCD201 is similar to a conventional CCD detector, with an area of 1024x1024 pixels^2 (each of 13 microns), a peak quantum efficiency of over 90% and very low dark current.

As reported in a forthcoming ESO Messenger article (see http://www.shef.ac.uk/physics/people/vdhillon/ultraspec/ultraspec_messenger.html), ULTRASPEC has the potential to revolutionise readout-noise limited spectroscopy. During our commissioning run (see below), for example, we effectively turned the ESO 3.6-m telescope into a 6.3-m telescope, purely due to the elimination of readout noise. The improvement is even greater if one takes into account the greater efficiency of ULTRASPEC provided by the essentially zero dead-time between exposures.

On which telescope(s) has your instrument been commissioned and/or used (scientific publications): Four nights of technical time were awarded by the Director of La Silla-Paranal Observatory to commission ULTRASPEC on EFOSC2 and to perform an on-sky evaluation of EMCCDs for astronomical spectroscopy. The run took place on 2006 December 1–4 and was a great success. We would now like to use ULTRASPEC to do science. This proposal is one of several being submitted to the OPC for period 80. If successful, we request that the OPC schedules it together with any other successful ULTRASPEC proposals in a single block of time early in 2008.

Total weight and value of equipment to be shipped: Total weight of ULTRASPEC and its ancillary equipment, including the 3 packing crates: 450 kg. Approximate value of equipment: 300 000 Euros.

Weight at the focus (including ancillary equipment): The ULTRASPEC (ESO) cryostat weighs approximately 30 kg when full with liquid Nitrogen. The SDSU CCD controller weighs approximately 10 kg. The ULTRASPEC electronics rack weighs approximately 100 kg. The resulting total is well within limits and did not cause any problems with telescope balance, pointing, tracking or guiding during the commissioning run.

Compatibility of attachment interface with required telescope focus: The cryostat used by ULTRASPEC is a standard ESO unit which has been used in the past on EFOSC2. Hence there are no compatibility issues. The SDSU CCD controller mounts on an ESO-supplied frame at the bottom of EFOSC2, and the ULTRASPEC electronics rack sits on a free bay in the Cassegrain cage using an ESO-supplied mounting plate. The cables between the rack and cryostat run through a hole in the centre of the floor of the Cassegrain cage, which acts as a simple cable twister. Photographs of the mounting arrangement can be seen in the commissioning report we submitted to ESO in January 2007:
http://www.shef.ac.uk/physics/people/vdhillon/ultraspec/eso_comm_report.html.

Back focal distance value: The EFOSC2 spectrograph requires the EMCCD used in ULTRASPEC to lie 14.0$\pm$0.5mm from the mounting flange of the ESO cryostat in which it is installed. Furthermore, the CCD must be flat to approximately 100μm with respect to this flange. These adjustments were made in the lab using a travelling microscope prior to commissioning and the resulting alignment proved excellent during on-sky tests in December 2006 (see the report on the commissioning run).

Acquisition, focusing, and guiding procedure: Due its high-speed readout, ULTRASPEC can operate with its full 2.4 arcminute field in a "TV acquisition mode", so acquiring targets and focusing is straight-forward using EFOSC2's imaging mode. Autoguiding is provided by an independent Cassegrain autoguider. More details are given in the report on the commissioning run.

Compatibility with ESO software standards (data handling): ULTRASPEC's system architecture closely follows the ESO model: the instrument has a Local Control Unit (LCU; a rack-mounted, dual-processor linux PC located next to the cryostat in the Cassegrain cage) which can be controlled over the ESO 3.6m LAN by any workstation that is able to open an xwindows session on it. There is no interface with the TCS/ICS, so the telescope, EFOSC2 and ULTRASPEC all run in a stand-alone mode. Further details are given in the commissioning plan we submitted to ESO in October 2006: http://www.shef.ac.uk/physics/people/vdhillon/ultraspec/commissioning.html.

Estimate of supplies and services expected from ESO (in person days): Having already had a successful commissioning run in period 78 on the ESO 3.6m, ESO technical support in period 80 will be limited to assistance with mounting and dismounting the cryostat, CCD controller and electronics rack at Cassegrain, and connecting our computer facilities to the ESO 3.6-m LAN. Further details are given in the commissioning plan.