1 Title: The WFCAM Transit Survey (WTS)

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1.1 Abstract: (10 lines max)

This WFCAM survey will identify and study rocky planets using the transit technique, by targeting low mass M dwarfs in the near infrared. This is a ground breaking opportunity. While the survey data itself can reveal the size of the planets, radial velocity follow-up will provide planet mass and density. Planetary atmospheric properties will come from transmission spectra and secondary eclipse measurements. M dwarfs provide a particularly sensitive probe for small planet transits, will show larger Doppler wobbles than higher mass stars, and have lower planet/star brightness contrast ratios. Indeed, for the lowest mass M dwarfs this survey could find planets that may be habitable. Interestingly, since the transit technique is based on relative photometry, this survey is currently and could continue to be conducted in poor weather conditions, ensuring a high efficiency for WFCAM observing. Other science products will include M dwarf variability, eclipsing low-mass binaries, new Plutinos and Kuiper Belt objects, and very faint high proper motion objects such as ultra-cool helium rich white dwarfs.

2 Description of the survey:

2.1 Scientific rationale:

It is of fundamental importance to understand the origins of life in the universe. A primary goal of modern science is to discover and characterise planets around other stars, where life might be able to take hold. A planet's habitability depends primarily on 2 factors; whether it is a rocky world or a gas giant, and whether it resides in the habitable zone around its host star, where liquid water may flow on its surface.

Radial velocity planet searches: The radial velocity (RV) technique has proved very successful in planet hunting, harvesting ∼180 planets in the last decade (Marcy et al. 2005). However, nearly all the host stars lie in the range 0.7–1.4 $M_\odot$. Stars less massive than 0.7$M_\odot$ become increasingly faint in the green-visible where the iodine cell provide reference lines. RV surveys (e.g. Delfosse 1998, 1999) have tackled small samples of M dwarfs (∼100). The Keck Doppler survey of the Berkeley group include 150 M dwarfs, while the Keck Hyades program of Cochran et al. (2002) contains a sample of 20 M dwarfs. Endl et al. (2003) have undertaken a dedicated M dwarf RV survey with HET, but found no planets around ∼100 targets (Endl et al. 2006). However, all of these surveys are limited to the earliest M dwarfs, and become rapidly incomplete beyond M2-M3. They are incapable of extending into the very late spectral types.

Planets around low-mass stars: Even with the difficulties of detecting planets around low-mass stars, some of the most interesting examples have been discovered around M dwarfs: GJ876 (Marcy et al. 2001) is a multiple planet system including a 7.5 $M_{\rm Earth}$ planet with a 2 day period (Rivera et al. 2005), and GJ436 (Butler et al. 2004) hosts a Neptune mass planet at a separation of 0.028AU. Beaulieu et al. (2006) report the discovery of a 5.5 earth mass planet orbiting a 0.2 $M_\odot$ M dwarf, from the microlensing event OGLE 2005-BLG-390Lb. The best candidate so far for an image of an extra-solar planet is the putative 5 $M_{\rm Jup}$ companion to the ∼25 $M_{\rm Jup}$ young M8 brown dwarf 2MASS J12073346-3932539 (Chauvin et al. 2005).

Recent theoretical predictions on the formation of planets around low-mass stars are of wide significance to the entire field of extrasolar and solar planetary science. Laughlin (2004) predict that the core accretion mechanism of planet formation results in only a few Jovian mass planets around low-mass stars, but instead many Neptune and terrestrial mass planets. The study of the frequency and distribution of planets around M dwarfs thus offers the possibility to discriminate between the two dominant theories of planet formation: core accretion (Pollack 1996) and gravitational instability (Boss 2004). In general, given that M dwarfs dominate the stellar population in number, it is clearly vital to fully probe their planet harbouring potential.

Planets transiting M dwarfs: The transit method is able to detect planets if the system is favourably aligned (i ∼90). Once per orbit the planet passes between the star and the observer, causing an occultation or transit that results in a dip in the light curve. RV measurements can yield precise planet masses, and detailed light curve measurements can determine planet radii. Planetary mass-radius measurements lead to constraints on their composition and atmospheric structure (e.g. Sato et al. 2005; Arras & Bildsten 2006), and likely evolution and migration history. Transmission spectroscopy also allows one to study planetary atmospheres (e.g. Charbonneau et al. 2002, Vidal-Madjar et al. 2003; 2004), and the study of secondary eclipses (e.g. Deming et al. 2005; Charbonneau et al. 2005; Deming et al. 2006) provides a direct measure of emission from planets, and may even allow constraints on the planetary surface flux distribution (Williams et al. 2006).

Searching for M dwarf transits is compelling for several reasons. There is a strong geometrical bias for transiting planets being close to their stellar hosts, which resulted in the identification of the transiting hot Jupiters discovered in optical transit surveys. However, the habitable zone around M dwarfs is much closer in (∼0.02–0.4AU) than for solar type stars, and the likelihood of habitable transits is much higher. The smaller radii of M dwarfs results in much deeper dips in the light curve for giant planet transits, and makes it possible to detect smaller planet transits. For example, an Earth radius planet orbiting a 0.08 $M_\odot$ star produces a transit of 1% depth as does a Jupiter radius planet orbiting a sun like star. Currently the only Saturn-like transit known is around a solar type star, and produces a 0.3% eclipse (Sato et al. 2005), at the limits of what can be measured from the ground. M dwarf transit sensitivity to rocky planets could be particularly rewarding, since the IMF of the known exoplanets rises towards lower mass, and a continuation of this trend would result in at least one rocky planet around every star. Radial velocity confirmation is also aided by the larger reflex velocity of a low mass host star. Yielding accurate planetary mass, radius and separation, the discovery of rocky planet transits of M dwarfs could thus, for the first time, allow us to unambiguously identify warm rocky planets.

The need for the WFCAM transit survey: Nearly all the emergent flux from M dwarfs is in the near infrared, and one can thus measure them out to the greatest distance at these wavelengths. Their intrinsic faintness requires a large scale survey to effectively probe for M dwarf planet transits. The wide field and sensitivity of WFCAM make it ideal for the task. Some of us (led by Hodgkin & Pinfield) are already conducting a "WFCAM Pilot Survey" on UKIRT (see Pinfield et al. 2006), and have demonstrated its potential for finding transits. We have shown that at low galactic latitudes (b), transits could be measured with just 2-3 mmag residuals (see Figure 1). This is in contrast to higher b, where we have found (using UKIDSS DXS data) that $\sim$10 mmag residuals are usual. This difference comes about primarily from the number density of available comparison stars used to construct light curves. If one has to measure the required large number of comparison stars over a significant area of an array, systematic errors (e.g. flat field variations) increase. Other systematics can result from a random timing of individual exposures (e.g. DXS), where for example, small changes in the pointing between exposures can change the intra-pixel sensitivity within a source. Well sampled light curves observed in a well structured sequence are clearly required to minimize such systematics and allow individual transits to be measured. If WFCAM is to effectively search for M dwarf planets, a dedicated transit survey at low b is required, which will provide a rich dataset for coordinated international follow-up and interpretation of planetary populations, by an already strong exoplanet community in Europe.

2.2 Immediate objective:

We propose to build on our pilot survey and commence the WTS in 2007, and continue to observe in flexibly scheduled poor seeing conditions (>1 arcsecond) over a 5 year period. The WTS is undemanding in this respect, and can effectively make use of such time without compromising the science objectives. Light curve analysis will be done using relative photometry, which is not significantly affected by poor or moderately variable seeing. Also, although well sampled light curve portions will be measured as part of a minimum-schedulable-block (MSB), a random timing of these blocks is quite acceptable (see Section 2.3), and is well served by this approach.

The WFCAM planet catch: To determine the sensitivity of the WTS to potential M dwarf planets, we have made a simulation of the survey. Precise predictions of the number of transits are difficult due to the relative novelty of the subject. The alignment probabilities as a function of separation are less good than around solar type stars because M dwarfs are smaller. However, we would recover this probability if M dwarf planets orbit their hosts closer in. This could be the case if the planetary system scales with primary mass – the inner edges of dust disks around young low-mass objects can be as close as $\sim$2 stellar radii (e.g. Luhman et al. 2005), and the known planet around the M dwarf GJ436 orbits at 14 $R_\star$. In light of this we consider separations from 0.006–0.06AU (or periods of $\sim$0.5–10 days).

For giant planets we have assumed that 1% of stars are hosts (the "planet fraction"; PF). This is the same as evinced by hot Jupiters around solar type stars, and is also reasonably consistent with the existence of the planets around GJ436 and GJ876. Small rocky planets could be much more common, and we thus model a range of PFs for these. We simulated a survey population of $\sim$20,000 M dwarfs ($M_J > 6$, J<16) which matches 2MASS star counts, using the luminosity function of Chabrier (2003) and the disk model of Zheng (2001). Stellar radii and masses were taken from the Lyon Group models. Companion planets were randomly assigned for 0.006-0.06AU separations to give a flat log(P) distribution. Planet radii were selected from $0.1\,R_{Jup}$ ($1\,M_{Earth}$) up to $1\,R_{Jup}$ ($1\,M_{Jup}$). Light curves of transits were modeled assuming random inclinations (Goldstein 1981), and *observed* (see Section 4) with WFCAM sensitivities (employing the expected systematic errors shown in Figure 1), assuming average seeing of 1.3 arcseconds. A planet is detected if we measure $\geq$4 separate transits, and obtain a combined in-transit signal-to-noise greater than 10 (see Section 4 for details on these criteria).

The results from our simulations are summarised in Table 1 and an example planet catch is shown in Figure 2. Note that we have also used the code of Gillon et al. (2005) to carry out an independent simulation, and find consistent results for both. In brief, if 30% of M dwarfs have close large rocky planets, we would expect to detect ∼10 of them. Even for a 10% rocky PF we would still find ∼3. The close Neptune-like catch remains significant even for a PF of 1–2% due to increased transit depth, and would yield ∼5 Neptune-like planets around M dwarfs. Approximately 15 Jupiter-like and Saturn-like planets could be discovered, although the Jupiter-like PF may be less than 1% if such planets do not form easily around M dwarfs.

Table 1: Simulated WFCAM M dwarf planet catch for different planet sizes and planet fractions (PFs).

Planets	Radius (R_{Jup})	Transits found (PF=planet fraction)		
		PF=30%	PF=10%	PF=1%
Large rocky planets	0.10-0.25	∼7	∼2	–
Neptune-like	0.35	–	–	∼4
Saturn-like	0.8	–	–	∼10
Jupiter-like	1.0	–	–	∼10

Figure 2 shows the separation–stellar mass plot for a WFCAM planet catch with PFs of 1% for Jupiter-like, Saturn-like and Neptune-like planets, and 30% for large rocky planets. It can be seen that all the transiting planets are at smaller separations than the classical habitable zone (Kasting et al 1993; enclosed by the dashed lines). However, these M dwarf planets will be tidally locked, and the habitable zone for such synchronously rotating systems is not simply a function of stellar mass. If a water trap forms on the dark side of such planets, then a low pressure atmosphere can maintain a dark side/terminator habitable region. Joshi Haberle & Reynolds (1997) have shown that for 100mb atmosphere, a habitable region could exists for orbits with 3 times the terrestrial insolation. This limit is indicated with a dotted line, and it is thus apparent that for a rocky planet PF≥30% the VTS could identify such potentially habitable planets around late M dwarfs.

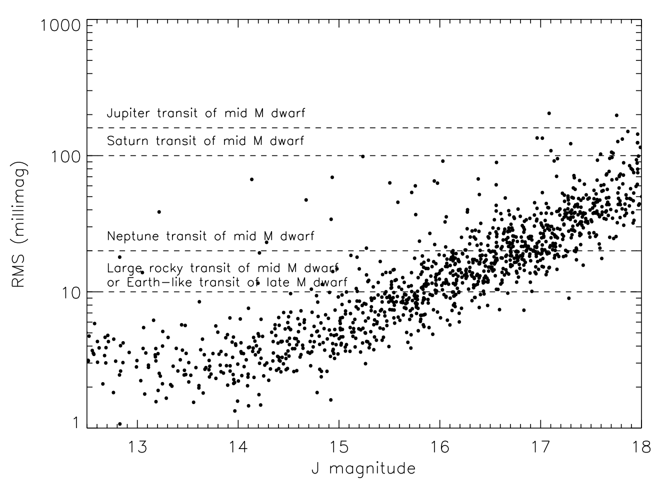

Figure 1: This RMS diagram is derived from 42 observations of one paw-print with WFCAM (from the current WFCAM transit survey). Each observation comprises 90 seconds of integration (9-point dithers). The cadence of the observations is 12 minutes (8 paw-prints are observed). We have averaged the data over 4 data points (the likely duration of a transit) to show our sensitivity. We achieve a precision of 2-3 mmags at the bright end, and ∼1% at J=16. The depth of various planetary eclipse dips are indicated with dashed lines.

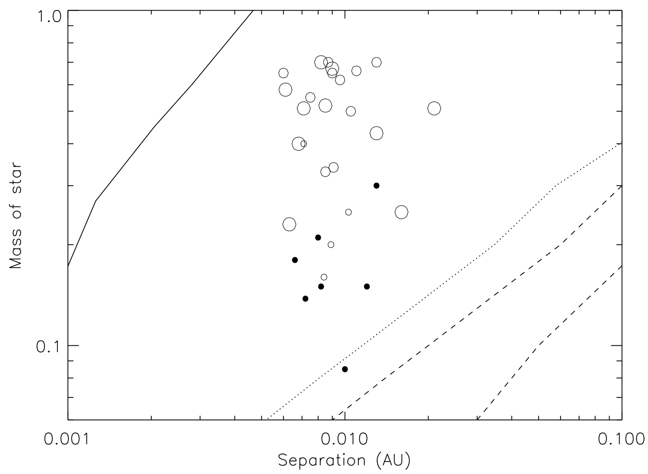

Figure 2: Simulated M dwarf planet catch for the WFCAM Transit Survey, with M dwarf PFs of 1% for Jupiter-like planets (large open circles) Saturn-like planets (medium open circles) and Neptune-like planets (small open circles), and 30% for 2.5 R_{Earth} large rocky planets (small filled circles). The simulated separation range is 0.006-0.06AU. The stellar surface is shown with a solid line. The classical habitable zone is indicated with dashed lines. A synchronously rotating inner habitable limit is indicated with a dotted line (see text).

2.3 Technical Justification: Observing Strategy

Observing conditions: The WTS will measure light curve data in the same way as our current WFCAM transit survey does, in a series of observing blocks that can be queue scheduled on UKIRT. We define our survey strategy to make use of randomly timed observation blocks, and this means that the WTS can take advantage of certain weather conditions. Our target stars are not faint, so we can make use of poor seeing conditions. About 15% of usable UKIRT time is expected to have J-band seeing worse than 1.0 arcseconds. This time is quite acceptable for the WTS, and will not compromise the science. Also, about 23% of usable UKIRT time experiences thin cloud. This time is also useful for the WTS, since our light curves will be measured using relative photometry. Accounting for current levels of eng/UH/Jap time, assuming that 75% of operational nights are "usable", and that, in the future, WFCAM will be on UKIRT for 60–100we estimate that ~19–31 WFCAM observing nights per year will experience seeing >1 arcseconds, and ~29–48 nights per year will be unphotometric. Therefore, a total of 44-73 nights per year are expected to experience poor seeing and/or thin cloud. We propose to carry out the WTS in this significant block of time (except for a single $ZYJHK_s$ exposure; see below).

Time per region: We define our general observing strategy based on our existing WFCAM transit survey. In this pilot survey we obtain 2–3 mmag accuracy within a transit time-scale (see Figure 4), and thus estimate that, for 1% eclipse dips of J≤14 M dwarfs, we will need to measure 4 separate transits to obtain a combined in-transit signal-to-noise of 10 (although note that large planets can cause much larger eclipse dips when transiting M dwarfs, and will be detected out to fainter magnitudes; see Figure 1). We have simulated the efficiency with which the WTS could achieve this 10-σ detection requirement, and find that 200 hours on each region of sky is efficient for the short period (0.5–3 day) transits we seek. A plot of the predicted survey efficiency is shown as a function of a planet's orbital period in Figure 4.

Light curve sampling: Well sampled light curve data is important to both effectively sample the transits and allow for any non transit signatures to be identified. We note that M dwarfs can show enhanced chromospheric

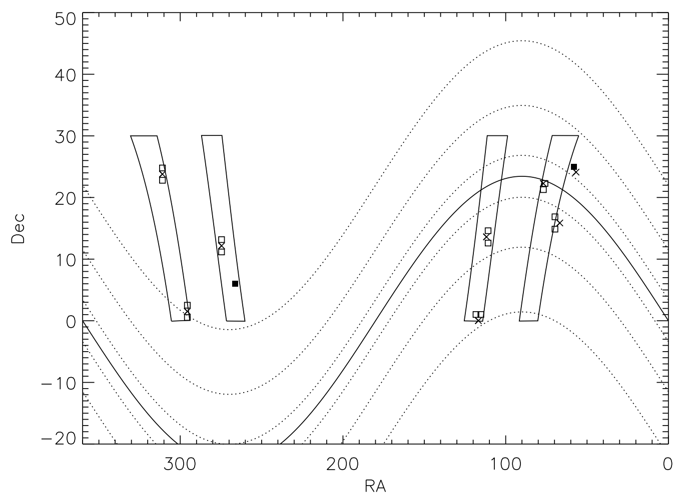

Figure 3: The location of the survey regions on the sky (shown as filled squares). Areas with $|b|$=10-20 and 0<Dec<30 are enclosed by solid lines (see Section 2.3). The following open clusters are indicated with triangles; Herschel 1, Alessi 44, Alessi 19, NGC 2395, Hyades, Platais 4, Alessi 4, Alessi 12, Pleiades. The ecliptic is shown as a solid line, with the extent of the classical Kuiper belt, the region in which Plutinos are found, and the scattered Kuiper belt (from Brown et al. 2001) shown as dotted lines.

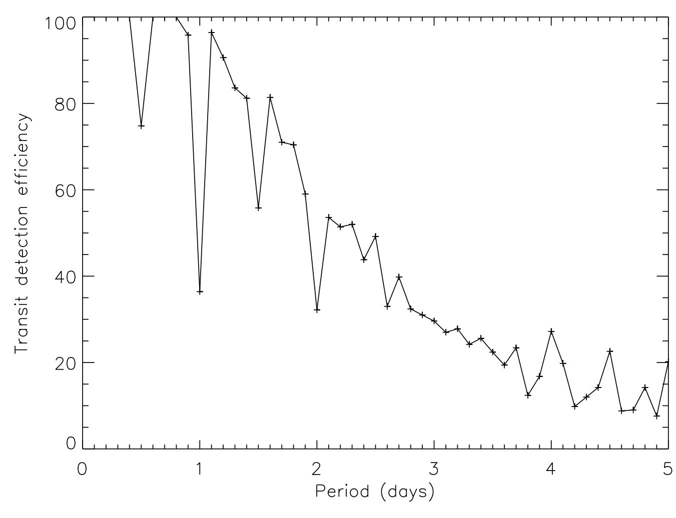

Figure 4: The simulated efficiency of the proposed WTS transit detection for 200 hrs on each region. A confirmed transit detection requires that at least 4 separate transits are measured, and a total in-transit signal-to-noise of at least 10 is obtained.

activity when young, and their light curves can show periodic quasi-sinusoidal modulations at the 1-2% level due to photospheric spots. However, it is relatively simple to distinguish and disentangle eclipse events from rotational modulation on the basis of shape and duty cycle provided one has well sampled light curves. Field M dwarfs do not show the kind of flickering/accretion phenomena that makes a transit survey in a star forming region so difficult (e.g. Caballero et al. 2004).

Sky coverage and cadence in an observing block: Although high cadence in an observing block is desirable, a balanced must be found that allows one to cover sufficient sky, and observe in an efficient manner. The WTS will use 12s exposures in an n=4 jitter-pattern at each paw-print position. The sky coverage in an observing block consists of 8 paw-prints (ie. 2 tiles or 1.5 sq degs). It takes $\sim$10 mins for the observing sequence to cover this region, and it will thus be repeated 6 times per hour for the full length of the observing block.

The length of observing blocks: Observing blocks will last 1 hour so that they can be readily selected by the queue scheduler when the weather conditions become appropriate. However, two hour light curves would be preferable for detecting complete transits, so back-to-back WTS block observations could be encouraged in the queue by raising the priority of an additional block (of the same WTS region), once the initial block has been started. Note, of course, that transits can always be searched for in isolated 1 hour blocks by phase folding the data.

Filter choice: We will observe our light curves in the J-band only, since M dwarf colours dictate that they are detectable out to the greatest distance in this filter. The only exception is a one-off single $ZYJHK_s$ image of each region in median seeing to allow both better identification of M dwarfs (photometrically) and the means to identify some sources that could be blended in the main survey images. This is only a small additional requirement ($\sim$1 night), but will be very useful when creating an optimal list of transit candidates.

Total time request: We propose that the WTS is conducted over 5 years. During this time the survey's poor weather niche should allow it to cover a total of 10–16 regions (each 1.5 sq degs), depending on the fraction of time that WFCAM is on UKIRT (60–100% respectively). In practice we will create 200hrs worth of observing blocks for each region, to measure the required light-curve data. Observing blocks for the first three regions will be uploaded into the UKIRT queue at the start of the first campaign year. These regions will be spread in RA so that at least one region is always observable at any time of year (this ensures that the survey can always take advantage of its poor weather niche). Observing blocks for new regions will be uploaded as previous regions (of similar RA) are completed. In this way, we will ensure that we obtain full light curve data on particular regions as rapidly as possible, which will minimize the science turn around time for the most exciting planet transits in the early regions. During the expected 44–73 poor weather WFCAM nights per year (average $\sim$9hrs/night), the WTS will complete $\sim$2–3.3 regions per year (for 60-100

Optimal coordinates for science and scheduling: We chose sky regions in the declination ranges $0 > \delta >$ 30. This range ensures that regions transit quite close to the zenith, and are observable for as long as possible during a night. However, this declination range slightly favours targets that will be more easily accessible to southern observatories as well as northern ones, to facilitate the widest range of followup (see Section 6). In order to meet the important requirement that the number density of background comparison stars is high (see Section 2.2), we chose regions with $|b|$=10-20. This is also beneficial because there are 2-3 times as many M dwarfs to J$\sim$16 at these galactic latitudes compared to the galactic cap (where the disk scale height reduces the number of more distant M dwarfs). However, we avoid $|b|$ <10 since high levels of contamination by reddened stars and giants make it difficult to select clean photometric M dwarf samples. To maximize WTS legacy potential we have located the majority of our regions near to open clusters (with ages of 100Myrs–2Gyrs and within $\sim$500pc). This maximizes the potential for serendipitous cluster transits and more general cluster science (e.g. variable stars, the low-mass IMF), while being careful to avoid young regions. We also ensured that a significant fraction of our fields lie towards the scattered Kuiper belt, to facilitate solar system science. With these constraints we have selected 16 regions (including 2 from our pilot survey), which are shown in Figure 3. Fifteen of our regions are in the vicinity of an open cluster, and ten are towards the scattered Kuiper belt.

3 Confirming transiting planets

3.1 Identifying false positives

The "false positives" are a major concern for transit searches, and it is vital to diminish the need for time consuming radial velocity follow-up on 8m telescopes, by removing as much contamination as possible. The main contaminants are eclipsing binaries with grazing geometries, transits of a small star in front of a large star, (e.g. a K dwarf in front of a giant) and finally eclipsing binary systems blended with the light of another star along the line of sight. We will address possible blending to some degree with our "median seeing" images (see Section 2.3), and carry out analysis on the photometric morphology of the light curves to search for evidence of blends and stellar companions (e.g. Drake 2003; Sirko & Paczynski 2003; Seager & Mállen-Ornelas 2003). However, results from OGLE follow-up indicate that the number of contaminants at the 1% eclipse dip level can largely outweight the planetary transits, and we will thus employ an efficient and thorough follow-up strategy.

Spectral typing: Low resolution optical or near infrared spectroscopy will confirm the spectral type of candidate transit sources. This will identify any giant star contaminants, and will also allow the mass and radius of candidate transits to be estimated, by placing tight constraints on the size of the stellar host. This task can be done quickly using a variety of 2–4m class telescopes. The spectral types will feed back into the WTS candidate transit list, allowing for the removal of contamination and the flagging of particularly interesting candidates.

Medium resolution RV studies: Medium resolution spectroscopy will be capable of rapidly identifying eclipsing binaries with grazing geometries using 4m telescopes, since the expected amplitudes are generally several tens of kms^{-1}, compared to a few hundred ms^{-1} caused by, for example, a Jupiter-mass planet orbiting an M dwarf.

Multi-band light curves: For blends however, the main star may show little or no velocity variation, suggesting the presence of a very low-mass companion. Multi-band photometric followup can be used to search for colour changes that will indicate a blended source where a transiting stellar companion is mimicking a planet. We will carry out multi-band photometric follow-up of candidates on a variety of facilities. Since our targets will be observable from southern as well as northern observatories, this planned followup includes OmegaCam/VST guaranteed time (GT) of the Observatory of the Ludwig Maximillian University in Munich and the Max-Planck Institute for extraterrestrial physics (Saglia, Bender), as well as GT of the Max-Planck Institute fuer Astronomie, Heidelberg, with the Wide Field Imager (WFI) on the 2.2m telescope on La Silla (Henning).

3.2 High resolution RV studies

We will carry out radial velocity follow up of our decontaminated transit candidates using several facilities world wide. The most challenging radial velocity measurements will be for potential rocky planet transits. However, we are aided by the relatively high reflex velocity of the low-mass M dwarfs around which such transits can be detected. For a $10\,\mathrm{M}_{\mathrm{Earth}}$ rocky planet transiting a 0.1–$0.25\,\mathrm{M}_{\odot}$ M dwarf at 0.01AU, we expect an M dwarf reflex velocity of $\sim$20-30 ms^{-1}. We know from our simulation that WTS can detect such transits around stars with J<14 (for which we will achieve the 2-3 mmag uncertainties necessary to measure 1% eclipses). Gemini and GranTeCan are gearing up with new high performance high resolution (e.g. R$\sim$42,000) near infrared spectrographs, whose science drivers are strongly motivated by the prospects of detecting low-mass planets around M dwarfs. These instruments will meet the challenge of measuring the radial velocity signatures of WTS rocky planet transits. Jones is leading the bid for the near infrared PRVS spectrograph on Gemini. Martín is PI of the proposed NAHUAL spectrograph for GranTeCan.

More massive Jupiter- and Saturn-like transits will produce M dwarf reflex velocities of >100ms^{-1}. We will measure such RVs with instruments like CRIRES on the VLT and NIRSPEC on Keck (we will have access to NIRSPEC through Martín for instance). We can also use UVES on the VLT to measure radial velocity signatures in the optical of giant planets around many of our early or brighter M dwarfs (e.g. Joergens, 2006). Some of us (Saglia, Bender) have a 7.5% share of the Hobby Ebberly Telescope (the HRS provides capabilities similar to UVES), and part of this time would be used to follow up WFCAM transit candidates.

3.3 Revealing the physics of confirmed planets

Once confirmed, the WFCAM planets will be a focus for a large variety of giant and rocky planet science. Detailed radius measurements (e.g. Wittenmyer et al. 2005) will reveal the planet density. Reflected light studies (e.g. Leigh et al. 2003) and emitted light measurements (Deming et al. 2005; Charbonneau et al. 2005) will constrain the physics of the planetary atmospheres. These studies will benefit greatly from reduced star/planet brightness contrast ratios. Also, transmission spectra (e.g. Ehrenreich et al. 2006; Narita et al. 2005) and the Rossiter effect (see Snellen 2004) can be brought to bear on the chemical composition of the planetary atmospheres. Such studies will make use of the latest instrumentation on large ground based telescopes and space based facilities such as Spitzer. They can also drive the development of future 20-30m class telescopes and will be ideal targets for the JWST, which could measure secondary eclipses with un-precedented accuracy.

4 Competing ongoing or planned surveys

Corot and Kepler will attempt to detect rocky planets around solar type stars from space, and Kepler will aim for Earth analogues in the habitable zone. A ground based M dwarf transit survey represents an extremely economical (by comparison) and yet complementary way to seek out habitable planets of a different ilk. The full extent of the habitable zone for different stellar populations needs to be properly investigated if we are to fully appreciate the scope of life bearing worlds.

There are a variety of ground-based optical transit surveys using telescopes with apertures of centimetres up to 4m (see Horne 2003). The very wide angle survey data is a particular challenge due to numerous systematic uncertainties. However, these surveys are beginning to beat down these systematics, and are succeeding in identifying giant planet transits of optically bright solar type stars (e.g. O'Donovan et al. 2006; McCullough et al. 2006; Collier Cameron et al. 2006). The smaller field optical surveys such as OGLE have less problems with systematics, although the transit community needed to learn important early lessons from OGLE in order to reduce false positives and identify transits around fainter solar types (eg. Pont & Bouchy 2006).

The benefits of moving into the near infrared to detect planet transits has been known for some time. Plavchan et al. (2005) are carrying out an M dwarf transit search using 2MASS calibration fields. These fields cover $\sim$4 sq degs, and were measured with 7.8s exposures by the 1.3m 2MASS telescopes. By comparison, the proposed WTS will cover $\sim$3 times the sky, with $\sim$4 magnitudes more sensitivity. It is most encouraging that even with the modest 2MASS transit survey parameters, two candidate M dwarf giant planet transits have been identified (Jura, private communication). But it is clear that the sensitivity and scope of this 2MASS survey is a long way short of providing the potential to detect populations of rocky planets, as WFCAM could.

There are two ongoing surveys (UKIDSS UDS and DXS) and two proposed VISTA public surveys (VIDEO and V-UDS) that can provide some near infrared light curve data, with the potential to detect M dwarf eclipses. However, UDS and V-UDS are for small areas of sky, and DXS and VIDEO would provide only limited light curve coverage. Also, importantly, all these surveys are at high galactic latitude. This latter point is key, since the number density of stars at high galactic latitude is insufficient to measure light curves with the accuracy to detect small planets. For instance, we have measured light curves using DXS data at $b=45$, and find 10mmag systematic errors (this is the level of an eclipse dip when a large rocky planet transits a mid M dwarf). Giant planet and brown dwarf transits of mid-late M dwarfs could be detected by such surveys, if such systems are sufficiently common, but the detection of smaller planet transits will certainly be beyond their capability.

We note that VISTA public survey time will not include a specific transit survey, since the VISTA public survey panel felt that the relatively focused science goals of such a survey were somewhat incompatable with the broader scope desired for a VISTA public survey. A near infrared transit survey carried out as a UKIRT/WFCAM Campaign program would thus be unchallenged by WFCAM's main rival, allowing UKIRT to lead the way in this new arena of planet hunting.

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5 Data management and resourcing plan

5.1 Preparation & Observing

Pinfield will be responsible for preparing the observing blocks, and inserting them in the UKIRT queue. The WTS consortium will contribute its fair share of UKIRT observers to carry out queue scheduled observations when WFCAM is on the telescope.

5.2 Data access via the WFCAM Science Archive

WTS data (as with the pilot survey) will initially be managed by the VISTA Data Flow System (VDFS). Data frames are transported to the Cambridge Astronomical Survey Unit (CASU) where they are processed using the VDFS pipeline. Processed frames and per-frame catalogues are sent over the internet to the Edinburgh Wide Field Astronomy Unit (WFAU) where they are ingested into the WFCAM Science Archive (WSA). The final stages needed to produce WTS survey products - Quality Control (QC) filtering, stacking, mosaicing, and band-merging - are the joint responsibility of WTS members and VDFS project staff. Although implementation is shared, the WTS consortium has prime responsibility for design of the QC processes and algorithms.

The aim is to release WTS data products in a staged manner, roughly every six months. Again, this is done in a carefully agreed collaborative procedure with the VDFS project. To date, one pilot survey SV-style data release (pending full QC) has been made - on Oct 26. This release provides the user with a basic ability to search for variable objects and extract light curves using the WSA.

5.3 Higher level data mining

Although WFAU will development some basic WSA tools to facilitate a range of time domain physics with WTS data, we will also lead the development of some additional WTS requirements (summarised in the table). To facilitate optimised WTS light curves, Hodgkin will lead the development of software tools and the optimisation of analysis techniques to extract the most accurate milli-mag light curves from the WTS data. These light curves will be placed in a WTS database in Leicester/ROE that will be set up by West. Afonso and Agrain have operational pipelines already constructed that will search the light curve data for transit signatures. Wheatley will also provide more general "Time domain data mining tools" for mining the light curve archive (making use of "WASP heritage").

Name	Function	Affiliation	Country
D. Pinfield	PI	University of Hertfordshire	UK
C. Afonso	Light curve analysis	MPIA Heidelberg	Germany
S. Aigrain	Light curve optimisation and clean-up	University of Cambridge	UK
S. Hodgkin	High quality light curve generation	University of Cambridge	UK
R. West	Time domain archive at Leicester	University of Leicester	UK
P. Wheatley	Time domain archive data mining tools	University of Warwick	UK

Expected data products: (1) Instrumentally corrected frames (paw-prints, tiles etc) along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames). (2) Statistical confidence maps for each frame. (3) Stacked image data for dithered observations. (4) Derived catalogues (source detections from science frames with standard isophotal parameters, model profile fitted parameters, image classification, etc). (5) Data Quality Control database. (6) Database-driven image products (stacks, mosaics, difference images, image cut-outs). (7) Frame associations yielding a survey field system; seamless, merged, multi-colour, multi-epoch source catalogues with global photometric calibration, proper motions (where appropriate). (8) Source re-measurement parameters from consistent list-driven photometry across all available bands in any one field. (9) Light curve database with data-mining tools.

6 Legacy Potential of the WTS

The general approach that we adopt for our transit survey is also extremely amenable to many other areas of time-domain astronomy. Since our observing strategy has some inherent flexibility, we have chosen to optimise the survey to facilitate the best science across a range of fields.

Plutino discoveries and new realms of the Kuiper Belt: The WTS also presents a remarkable opportunity to probe the Kuiper Belt region of our Solar system, and a significant fraction of the survey area has been chosen to be towards the Kuiper Belt (see Figure 3). So far only 931 Kuiper Belt Objects (KBOs) have been discovered out of a suspected 10^5 objects (>100km in size) that are likely to inhabit the outer solar system. These icy KBOs retain a record of the earliest stages of solar system formation. Given the rate of motion of KBOs and the observing strategy employed by the WTS (see Section 2.3), we expect to be able to identify and follow KBOs for several months, providing orbit determination. We expect to find ≥300 new KBOs over the course of the 5 year survey. We will also be able to detect rotational signatures of elongated KBOs in WTS light curves, providing measurements of spin rate, shape and size. Currently, only 2% of the known KBO population have published rotational light curves, so the WTS could potentially increase this number by a factor of ∼16. Studies of the statistical properties of KBO rotation are suggestive but based on low numbers (e.g. Snodgrass et al. 2006). A well constrained KBO period cut-off, for instance, would have important implications for modeling their internal structure (cf. Weissman 2005).

There is also the exciting possibility of detecting objects that are larger than Pluto. Indeed, one such object was recently discovered (Bertoldi et al. 2006), provisionally designated 2003 UB313. With a limiting magnitude (for a typical nightly image stack) of J∼20.5-21, the WTS could easily detect new objects like 2003 UB313 out to ∼160AU, much further than the 92AU at which 2003 UB313 was discovered.

Low-mass stars and brown dwarfs: Our WTS light curve data will provide an unprecedented sample of field M dwarf rotation curves. Greatly increased numbers of measured M dwarf periods and spot covering fractions should significantly improve improve our understanding of the stellar dynamo for fully convective objects (e.g. Chabrier & Kuker 2006), with its implications for angular momentum evolution and disk-star interactions. A large variety of other types of stellar variability could also be studied using WTS data (e.g. Eyer 2006). There is a large potential for discovering low-mass eclipsing binaries in the WTS (some of which could be in open clusters and thus have well constrained ages; see Section 2.3). The recent discovery of a young eclipsing brown dwarf binary (Stassun et al. 2005) allowed the empirical testing of our theoretical understanding of the physics of low mass objects. The WTS will monitor ∼6000 late M and early L dwarfs (see Reid et al. 2004) to J∼18, and it is likely that more very low-mass eclipsing binaries would be found.

Searching for the faintest white dwarfs with high proper motion: Since WTS observations of each region of sky will be spread across 2 years, deep high proper motion searches will be able to probe for interesting populations. For example, the MACHO survey (Alcock et al., 2000) and a proper motion survey for population II white dwarfs by Oppenheimer et al. (2001) sparked a lively debate about whether white dwarfs contribute a large share of the (stellar) dark matter of the Milky Way. More recent results (e.g. Pauli et al. 2006) indicate that white dwarfs contribute more mass than previously thought, but not as much as suggested by the initial MACHO and Oppenheimer studies. However, all systematic surveys for cool white dwarfs were performed in the optical. This imposes a strong bias for the detection of hydrogen-rich white dwarfs, whose optical fluxes are much enhanced compared to their redder counterparts with helium-rich envelopes (e.g. Hansen 1998).

It is possible that a high amount of stellar dark matter could be locked up in cool He-rich white dwarfs. The best chance to detect these objects is as high proper motion objects in a deep infrared survey. Although very faint, multi-band photometric follow-up will be capable of confirming the spectral morphology of helium rich white dwarfs. We simulated the local white dwarf population based on the results of Pauli et al. (2006). Our simulation predicts the detection of a few He-rich white dwarfs in the WTS, *if* their space density is that extrapolated from the observed white dwarf population. However, the WTS will be able to put strong constraints on any excess population of cool He-rich white dwarfs that might contribute to galactic dark matter.