UKIDSS first two–year plan

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1 Background

This paper for the UKIRT Board presents a two year plan for the start of the UKIRT Infrared Deep Sky Survey (UKIDSS).

The full scientific case as submitted to the UKIRT Board in April 2001 and revised in November 2001 can be found on the UKIDSS web page (http://www.ukidss.org/sciencecase/sciencecase.html). The UKIRT Board meeting of December 2001 approved all five components of the UKIDSS proposal – the Large Area Survey (LAS), the Galactic Plane Survey (GPS), the Galactic Clusters Survey (GCS), the Deep Extragalactic Survey (DXS), and the Ultra Deep Survey (UDS). The proposal made a full scientific case but the details of implementation are still under development. This paper concentrates on setting priorities for an initial two year plan, but also begins more concrete planning, choosing field locations, modelling scheduling, and considering how to cope with variable seeing and non–photometric conditions.

Several factors determine our approach. (i) Although all five survey components were approved, the Board expects the programme as a whole to be under rolling review. The two year plan will determine an initial allocation. (ii) Both the Board and the Consortium are keen that science payback shouldn't wait seven years. The implementation plan should be designed to show significant results in two years. We go further than this and look for goals over six months, and during commissioning. (iii) Our new relationship with ESO means that it is in everybody's interest to consider field selection carefully in the context of VLT follow–up, i.e. to consider more southerly fields. We also consider demand for follow–up observations with the UKIRT instruments UIST and Michelle. (iv) The Board expressed a clear priority order for the survey components (LAS, GCS, GPS, DXS, and then UDS).

The working groups established for each survey component produced an implementation proposal which they presented to a full consortium debate on April 28th 2002, which arrived at an agreed plan. The full working group reports can be found at http://www.ukidss.org/2yrplans.tar, on the UKIDSS web page. The CSS (Steve Warren) then modelled the survey scheduling, and together with the survey heads produced a shortened version of the survey component plans, which we present here.

The layout of this paper is as follows. §2 presents a summary of the two-year plan and lists the action items for the Board. The succeeding sections provide the details that are summarised in §2. In §3 we present the results of a realistic calculation of how the surveys can be scheduled. §§4–8 contain the detailed proposals for each of the five survey components.

2 Summary of proposal

2.1 General points

We have produced a proposal which we feel responds well to the points made by the Board in December 2001. Field selections and filter choices have been agreed and the scheduling for the first two years considered in detail. These plans are based around science goals to be delivered in two years, in six months, and during commissioning. We have also responded to the priority order set by the Board, in that the fraction of each survey completed in two years is not the same – the LAS and GCS proceed significantly faster than the rest. Details are provided below.

At the December 2001 meeting the Board indicated that UKIDSS could expect an initial annual allocation of between 40 and 50% of all UKIRT time, after subtracting engineering time. Therefore we have based our planning around an allocation of 145 nights per year ($365 \times 0.9 \times 0.44 = 145$), or 290 nights for the first two–year plan. At their meeting in April the Consortium agreed the two–year plan proposal, which divides the 290 nights between the five surveys as listed in Table 1. The 290 nights is a fraction 0.31 of the total requested allocation. The proposed fractional completion of the individual surveys in the two–year plan is shown in the last column of Table 1 and ranges between 0.41 (for the GCS) and 0.21 (for the UDS). This is broken down in more detail in Table 2 which details areas and filters for each survey.

Survey	6.5 yr plan	2yr plan	Fraction completed
LAS	262	105	0.40
GPS	186	57	0.31
GCS	74	30	0.41
DXS	118	36	0.31
UDS	296	62	0.21
Total	936	290	0.31

Table 1: Summary of requested nights by survey in this two–year plan. The fraction completed is calculated as the fraction of the time required to complete the survey. Note that the total number of nights required for the GCS in the 6.5-year plan has shrunk from 84 to 74 nights, because of adjustments to the list of targets.

The locations of the fields to be observed in the two–year plan are plotted in Fig. 1. There follows a paragraph on each survey picking out the important issues that have steered the design of the two–year plan.

2.2 Large area survey

For the Large Area Survey (LAS), the multi–colour selection is crucial to achieving early science goals – detecting rare objects such as very low mass brown dwarfs, and very high redshift quasars. We therefore keep a full filter set (YJHK) in the two year plan, and execute a single pass in all bands, noting that in any case the minimum baseline for proper motions is $>$ 2yrs. We maintain the SDSS overlap, but define the boundaries as southerly as possible

Survey	Filter	Area $\square^\circ$	Mag. reached (Vega)	Fraction completed
	Y		20.5	0.50
LAS	J	2000	19.7	0.25
	H		18.8	0.50
	K		18.4	0.50
	J		20.0	0.43
GPS	H	780	19.1	0.43
	K		19.0	0.14
	H_2	300	...	0.33
	J	460	19.7	0.33
GCS	H	460	18.8	0.33
	K	1400	18.4	0.50
	J	12.6	22.5	0.36
DXS	H	0.0	...	0.00
	K	12.6	21.0	0.36
	J	0.77	24.0	0.16
UDS	H	0.0	...	0.00
	K	0.77	23.0	1.00

Table 2: Details of areas and fractional completion in each filter for the two-year plan, for each survey. The fraction completed is calculated as the fraction of the time required to complete the survey i.e. if the area surveyed in the two-year plan reaches the final depth then this is also equal to the fraction of the final area completed.

to maximise VLT follow–up, as recommended by the Board. Because of the short single–pass exposures, this survey is particularly vulnerable to variations in seeing and transparency. Because of this we plan to design three strips of differing seeing quality, and to use non–photometric time to make first–epoch J–band passes outside our prime area. We have also adopted the Board's suggestion to adjust the survey area to provide broader RA coverage. We have not considered contingency plans for the possibility of poor Y response of the arrays, awaiting the measurement of the array q.e. later this year. Y depth is essential to the cool dwarf searches. If the q.e. of the Y band is low an alternative use of non–photometric conditions could be additional Y–band exposures to increase the depth.

2.3 Galactic Plane Survey

For the Galactic Plane Survey (GPS), the top priority is given to the inner galaxy, keeping to very low galactic latitudes but covering a wide range of longitude. We agree with the Board that it is particularly important to maximise overlap with the SIRTF GLIMPSE survey at $3 - 10\mu$m, and to push coverage further south. Good colour coverage is important. The strategy in the first two years is therefore to do a "thin disk" survey, covering only $|b| < 1$ but a large range of longitude, but at the same time to do two "fat blocks" with $|b| < 5$ and restricted longitude range. We need to begin the H2 survey of the Taurus–Auriga–Perseus region, to maximise the proper–motion measurement time baseline. In line with the lower priority given to this element of the survey by the Board we defer this first pass to year two.

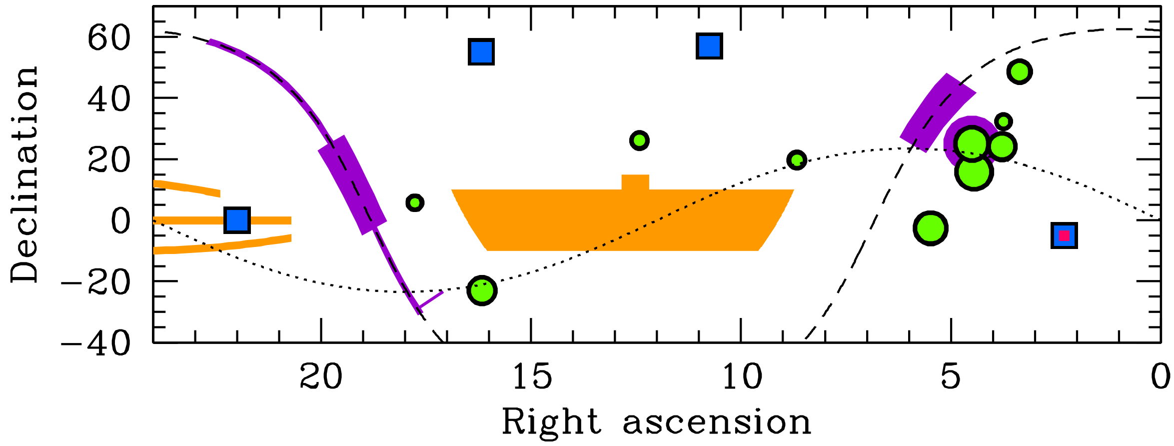

Figure 1: Locations of the fields in the two–year plan. The colour codes for the different surveys are: LAS orange, GPS purple, GCS green, DXS blue, UDS cherry. The details of the various fields are provided in the sections covering each survey. The dashed line marks the Galactic plane and the dotted line marks the ecliptic plane.

2.4 Galactic Clusters Survey

For the Galactic Cluster Survey (GCS), our approach has been to prioritise the cluster list, with a view to maximising the improvement in the sub–stellar mass function in the first two years. (The cluster list has also been reviewed to improve southern follow–up.) The first priority is observation of all the targets to get first epoch coverage at K. However this is fairly easily done, and so we also pick the top priority targets to cover at J and H. Good seeing will be used for K–band observations, and less good seeing for the JH. Non–photometric conditions will be used for astrometry.

2.5 Deep Extragalactic Survey

There has been a small but significant change in the strategy for the Deep Extragalactic Survey (DXS). The 35□° is now divided between four fields rather than three, with two fields in the north and two in the south. This is a consequence of balancing two strong opposing forces. To the south there is the new opportunity for deep spectroscopy with the VLT. To the north a fruitful synergy between UKIDSS and the AMI S–Z group at Cambridge is developing that is focused on the primary goal of the DXS, the evolution of the abundance of galxay clusters. The DXS requires fields covering a few to several square degrees with existing or planned multiwavelength coverage, and low cirrus. Optimising these requirements gives the final choice of fields is: the Lockman Hole, ELAIS N1, VIMOS–4, and the XMM–LSS field (with the UDS at its centre).

2.6 Ultra Deep Survey

For the Ultra Deep Survey (UDS) the key to the main science goals is the unprecedented area at such depth. For the two year plan we therefore drop the multi–filter coverage and aim to reach the full single band depth of K=23 over three quarters of a square degree, and also to reach J=24 over the full area, which is 1 mag. short of the target final depth. This is the only case where we are opposed to a suggestion of the Board, which recommended a single pointing rather than a filled in tile. Our reasoning is provided in §8. The field selection was clear – the Subaru/XMM Deep Field, which will have superb matching optical and X–ray data, and is accessible to the VLT. To reach this depth, we also need to ask for as much good seeing as possible on this field. This inevitably restricts the time devoted to this survey compared to the others, but should be enough to achieve our aim of a single contiguous K=23 field.

2.7 Scheduling

Given the field locations, we then considered the scheduling of time, using a simple algorithm based on a 216 zone approximation, and working within a maximum airmass of 1.5. Several things came out of this analysis.

(i) The spike in the RA distribution caused by the UDS is a bit of headache. This in itself restricts how much time can be devoted to the UDS, regardless of Board priorities.

(ii) This problem is accentuated by the fact that in order to keep good seeing, UDS cannot be observed too far over. If UDS accepts only the best 60% of the seeing, our algorithm finds that only 78% of the requested UDS nights get done. To get nearly all the requested time, UDS needs to accept 80% of the seeing distribution.

(iii) No solution can be found for a uniform distribution of nights. The requested distribution of nights over the year which does provide a successful solution is shown in Table 1. It peaks in the winter and is lowest in July and August. The other variables under UKIRT control are (a) the times when WFCAM is scheduled, and (b) the RA distribution of PATT nights. It is clear that UKIDSS and PATT scheduling must be solved simultaneously, and that PATT observers will have to accept a probability rather than guarantee of observation of a given field. It may be wise to make an early PATT call to assist modelling.

(iv) The WFCAM scheduling blocks obviously make a huge difference, and it seems desirable that WFCAM on–time should be concentrated in the winter. A range of models with different WFCAM–block patterns should be tried.

(v) DXS and UDS can use non–photometric time, but given the RA distribution, not all such non–photometric time is useful. It is therefore very important that there is a non–photometric backup programme for the LAS, GPS, and GCS.

2.8 Follow-up UIST and Michelle observations

The GPS element of UKIDSS could produce significant demand for follow-up observations using the UKIRT instruments UIST and Michelle, requesting perhaps 30 nights per semester. The demand from the LAS and GCS will be smaller, totalling no more than 10 nights per semester, primarily for UIST spectroscopy of the brightest brown dwarfs discovered.

There is unlikely to be significant demand for UIST or Michelle to observe DXS or UDS sources.

2.9 Board actions

The Board is invited to:

- Comment on the proposed relative allocation of nights between the five UKIDSS elements in this two year plan.
- Comment on the chosen combinations of depth/area/filters for each survey.
- Comment on the various goals listed to be achieved at commisioning / 6 months / 2 years.
- Reconfirm the allocation of 290 nights to the UKIDSS first two–year plan.
- Indicate their support for the UDS by agreeing the principle of scheduling WFCAM more heavily in months when the UDS is observable, over the lifetime of the UDS.

3 Implementation issues

The two–year plans for each of the surveys have been designed with regard only to the total time required and without consideration of the feasibility of scheduling the observations. In this section we examine the relevant issues. In §3.1 we describe a simple algorithm used to model the observing sequence. In §3.2 we apply the algorithm and examine the consequences of the RA and Dec distribution of the time requested, of the desirability of good seeing for the UDS, and of the requirement for photometric conditions for the LAS, GPS, and GCS. §3.3 summarises the conclusions of this study.

3.1 Observing sequence algorithm

The program attempts to model in a reasonably realistic way the actual sequence of observations. Firstly the sky in the declination range $-30^\circ < \delta < +60^\circ$ is gridded in units of RA of $1h$ and units of Dec of 10° into 216 'zones'. The two–year plan is specified by the number of requested clear hours in each zone for each survey i.e. there is a database with entries of observing hours for $5 \times 216 = 1080$ zones. A night is assumed to be 10 hours long plus a sinusoidal annual variation of amplitude 1.3 hours. Each hour of each night is assumed to be 70% clear i.e. on an average night there are 7 clear hours. The total observing time to schedule is 2030 clear hours, or $2030/7 = 290$ nights. At any particular hour on a night scheduled for UKIDSS the programme searches the database for the most urgent zone and observes it. 'Most urgent' is defined below. Since at this time we do not know the demand for PATT open time or the distribution of those fields, we cannot answer all scheduling questions. Instead we have sought a solution to how we can observe all the UKIDSS zones at reasonable airmass with a distribution of allocated observing nights that makes the scheduling of an additional substantial allocation of PATT time feasible. The result is the requested distribution of UKIDSS nights by calendar month. For the present we have not considered the effect on the scheduling of the variation of sky brightness in different bands over the night, nor seasonal seeing variations.

We seek a distribution of the 290 nights over the 12 calendar months (i.e. summed over the two years) that allows all the zones to be observed – and since the number of nights matches the time requested this would mean there is no time wasted. We started by trying a uniform distribution of nights by month i.e. $290/12 = 24.2$ nights per month, but this proves unsatisfactory. This distribution was then adjusted in order to complete all the zones, and this gives the UKIDSS request for nights, each calendar month, summed over the first two years of observations. Obviously the request must be less than 60 nights for any calendar month, and should not contain spikes.

To define 'most urgent' the first algorithm we tried was simply to observe the zone which, at the particular hour in the night, is at the lowest airmass. However it soon became apparent that to have a chance of scheduling the RA spike caused by the UDS one must immediately move to the UDS when it is observable i.e. not waste time on other zones that could be done at another time. The current algorithm, instead, defines the 'most urgent' target as the zone with

$$\min[\mathrm{airmass} * *2 - \mathrm{const.} * \log(\mathrm{hours\ requested\ left})]$$

A zone is only observed if it lies at airmass less than a specified maximum value.

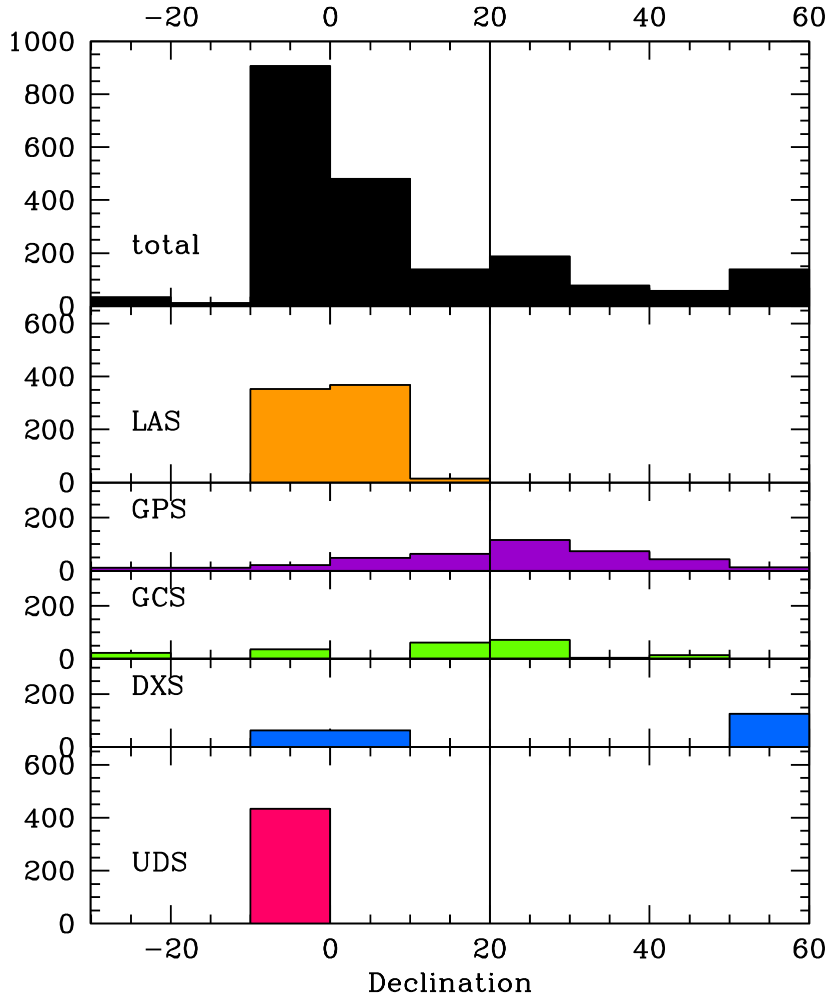

Figure 2: Distribution over declination of the 2030 clear observing hours requested, by individual survey, and summed over the five surveys. The line at $\delta = 20°$ marks the latitude of UKIRT. This plot emphasises the accessibility to the VLT of the majority of the two–year plan fields.

3.2 Analysis of two year plan

The marginalised RA and Dec distributions of the requested hours are shown in Figs 2 and 3. There is some flexibility in the choice of LAS fields (§4) so we have included the section of the southern SDSS stripes between 20 and $24h$ (Fig. 5) to provide a slightly smoother RA distribution. We have set the requirement of scheduling more than 95% of every survey without going above airmass 1.5, with a distribution of requested nights that can be achieved without frequent instrument changes, and without using all the nights available at any time of the year. At airmass 1.5 the two most southerly fields, the Scorpio cluster (in the GCS) and the Galactic centre (in the GPS), are both reachable.

3.2.1 The problem of the RA distribution

We are unable to achieve the above goals when the 290 nights are allocated uniformly over the calendar. There are insufficient nights to complete all the zones in the range $2h < RA < 5h$,

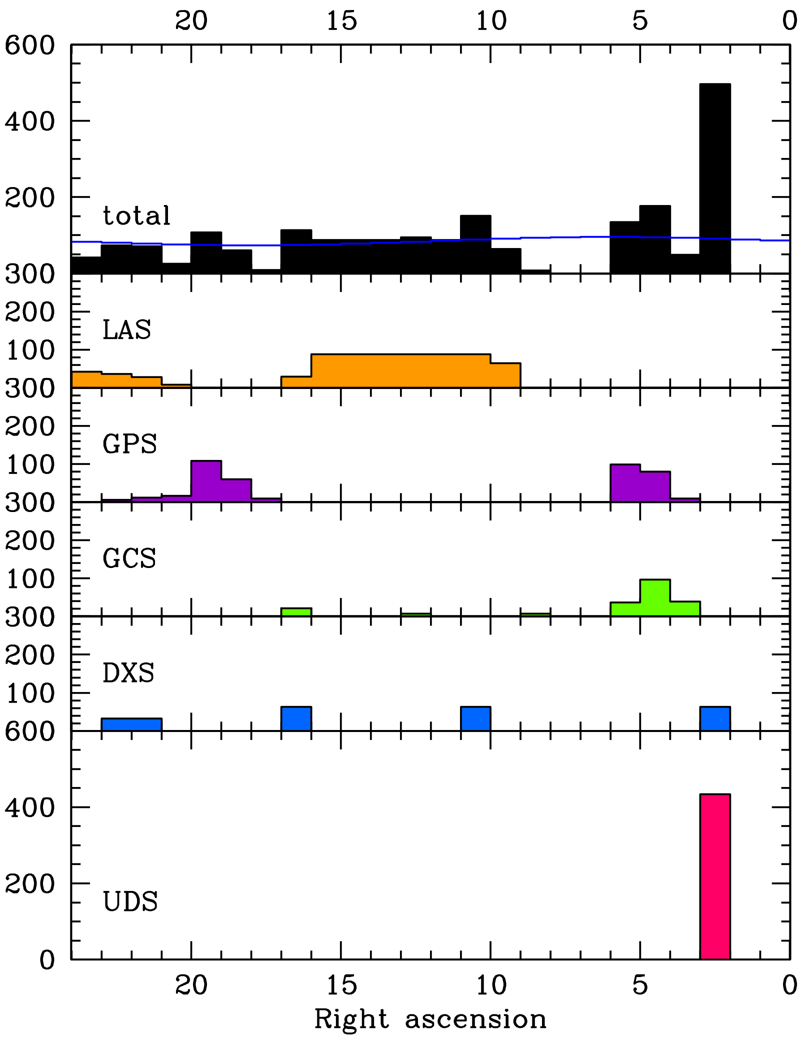

Figure 3: Distribution over RA of the 2030 clear observing hours requested, by individual survey, and summed over the five surveys. For the histograms the X axis is RA (coordinate). For the blue line in the top plot the X axis is RA(time) i.e. the time at which that RA is overhead at midnight. The line plots the number of hours available if the 290 nights are distributed uniformly over the 12 months of the calendar.

so that 7% of the surveys are not completed, 147h out of 2030h. The GCS is most affected, being only 80% complete. Correspondingly the telescope is idle for a substantial fraction of the time that the range $18h < RA < 24h$ is overhead. This is due to the spike in the RA distribution caused by the UDS, and the relatively small number of requested hours in the RA range 18 to 24h.

The problem of the spike due to the UDS will remain over the lifetime of UKIDSS. In fact it will be more severe for later two–year plans because (i) the UDS receives substantially less than its proportional allocation in the first two–year plan, and (ii) the southern LAS fields between 20 and $24h$, which smooth the RA distribution, are used up in the first two–year plan. One solution could be to engineer the RA distribution of PATT fields to smooth the overall WFCAM RA distribution, but this is surely not a satisfactory answer.

It is possible to solve the problem by scheduling WFCAM more often than average from October to December, and less often from July to September. Therefore to deal with the spike

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
24.2	24.2	24.2	24.2	24.2	20.2	12.1	12.1	20.2	36.2	36.2	32.3

Table 3: Requested number of nights, by month, over the first two years of UKIDSS. This is the summed number of nights over two years, so that, for example, for April 12.1 nights in the first year and 12.1 nights in the second year would match the requirement. The numbers in the table, then, are the product $2 \times N(month) \times G(WFCAM) \times G(UKIDSS)$, where $N(month)$ is the number of days in the particular month, $G(WFCAM)$ is the fraction of time WFCAM is on the telescope in that month averaged over the two years, and $G(UKIDSS)$ is the fraction of the WFCAM time given to UKIDSS over the same period. The numbers listed here correspond to the blue line in Fig. 4 i.e. we have simply mapped RA(time) to calendar month.

due to the UDS we increased the number of nights allocated between 0h and 6h RA(time) from 24.2 to 36.3 nights per calendar month, and decreased the nights between 18h and 24h RA(time) from 24.2 to 12.1 nights per calendar month. Here RA(time) means the date when the particular RA is overhead at midnight. With the airmass limit of 1.5 we can now schedule 98% of the fields. The average airmass of observation is 1.13, which seems very satisfactory. Translating between RA(time) and calendar month gives the schedule of requested nights listed in Table 1.

The choice of VIMOS4 as the fourth DXS field helps this solution. It acts as a counterweight to the UDS by providing a target at the beginning of nights in which the UDS is overhead in the middle of the night. Alternative fields such as NOAO–DWN ($14h32m$) or ELAIS–N2 ($16h36m$) cause a second, less severe, problem of too much time requested in the RA range $13h - 17h$.

The LAS southern SDSS stripes, from 20 to $24h$, also act as a counterweight to the UDS. But they will be used up in the first two–year plan. This points to a future difficulty. As stated above the problem of the spike in the RA distribution caused by the UDS will become more severe in the later years of UKIDSS. If WFCAM is on the telescope more often than average from October to December the UDS can be completed. But to use the telescope efficiently will require further counterweight fields approximately 5h either side of the UDS i.e. near $22h$ and $7h$. The UKIDSS fields in these RA regions will be exhausted well before the completion of the UDS. Therefore we recommend a pre–call for proposals to estimate the likely PATT demand over RA.

3.2.2 Good seeing for the UDS?

Is it possible to schedule the UDS only when the seeing is good? To answer this question we suppose that the UDS accepts the best 60% of the seeing, but that if the seeing is worse the UDS is not observed. Then, following the same scheduling algorithm, we find that only 78% of the UDS time is scheduled. If the seeing limit is relaxed to the best 80% the proportion scheduled improves to 100%. This suggests that the UDS cannot afford to place strong limits on the seeing conditions, but that rejecting the worst 20% seeing conditions is acceptable.

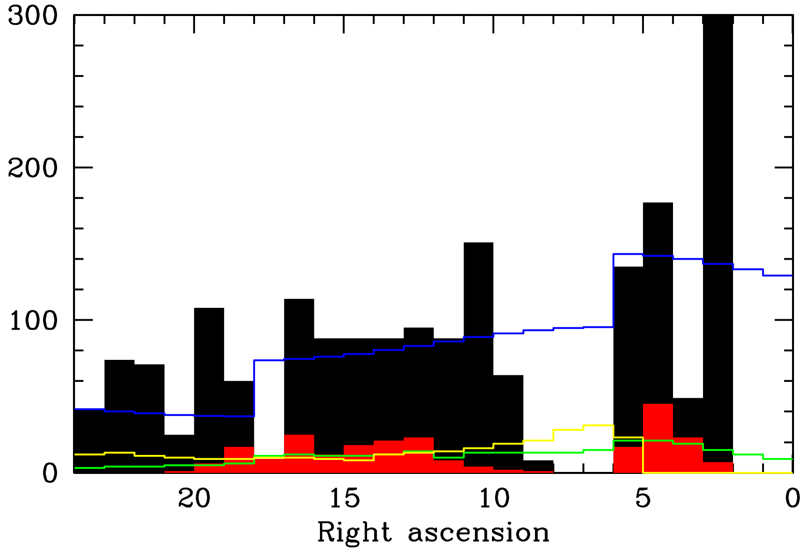

Figure 4: Results of the analysis of using non–photometric time, assuming that 70% of clear time is photometric. The x axis represents both RA(coord) and RA(time). The black filled histogram is the distribution of requested hours over RA(coord), and is the same as the black histogram at the top of Fig. 3. Note that in the above figure the spike between 2 and $3h$ in fact extends up to 497 hours. The red filled histogram shows the distribution of requested hours over RA(coord) that could not be scheduled. The blue line plots the number of UKIDSS scheduled hours over RA(time) (Table 3), and the green line plots the distribution of scheduled hours that were unusable as a function of RA(time). Finally the yellow line plots the distribution over RA(coord) of the unused time. In other words the yellow line shows which fields were overhead at a time when the telescope could not be used – because although there were fields which could be reached they required photometric conditions.

3.2.3 Non–photometric conditions

The DXS and UDS fields do not require photometric conditions since the depth is built up from repeat observations, only one of which need be taken in photometric conditions. The LAS, GPS, and GCS include passbands where only a single exposure is planned. Without some sort of bootstrapping of the photometry (e.g. from 2MASS, or overlaps, or making assumptions about the colours of stars), which we consider unsatisfactory, these fields must be observed in photometric conditions. Therefore we considered what impact this has on the schedulability of the surveys. Is it possible to limit observations to only the DXS and UDS fields when conditions are non photometric and still schedule the observations efficiently?

To answer this question we kept the distribution of nights scheduled as shown in Table 1, but made the assumption that on average conditions are photometric 70% of 'clear' time. In other words in an average 10 hour night there are 7 clear hours, of which 4.9 are photometric and 2.1 are non photometric. For this calculation we also made no restrictions on the seeing for the UDS. With these assumptions, running the program with no other changes we found that the DXS and UDS are scheduled satisfactorily, as before. However for nearly 40% of the non–photometric time there are no fields to observe i.e. 40% of the non–photometric time, or 12% of the total time is wasted.

These results are summarised in Fig. 4. Summed over the LAS, GPS, GCS, these three surveys are only 83% complete. Therefore we consider it essential that there is a backup programme strategy for the three photometric surveys so that LAS, GPS, and GCS fields can be usefully observed during non–photometric conditions, if there is no suitable DXS or UDS target reachable.

3.3 Summary of recommendations

1. WFCAM should not be scheduled uniformly but will need to be on more frequently than average for the RA(time) range 0h to 6h and less frequently in the RA(time) range 18h to 24h. Because this difficulty is caused largely by the UDS this recommendation applies to the lifetime of UKIDSS and not just the first two–year plan.

2. It is unlikely to be possible to observe the UDS only in conditions of good seeing without making unreasonable restrictions on the RA ranges that PATT observers can apply for, and on the times when WFCAM must be on the telescope. We recommend that the UDS reject only the worst 20% seeing.

3. The LAS, GPS, GCS need a strategy for usefully observing in non–photometric conditions, otherwise too much of this time is wasted.

4. A pre–call for proposals to estimate PATT demand, and likely target fields, would be very helpful in planning WFCAM scheduling.

4 The UKIDSS Large Area Survey Two Year Plan

4.1 Introduction

The LAS will cover $4000\square^\circ$ in $YJHK$ to $K = 18.4$, requiring 262 nights. The nominal proportional allocation for the first two years is 90 nights, and the consortium proposal is for 105 nights. The LAS will be completed in two stages. The first stage is a single pass in $YJHK$ over the full $4000\square^\circ$. The second stage is an additional pass in J over the same $4000\square^\circ$, for proper motions, with a baseline of at least 2 years. The LAS 2–year plan is to complete $2000\square^\circ$ (50%) of the first stage. The field locations for the two–year plan are plotted in Fig. 5.

The principal goals of the LAS are 1: surveys for the coolest T+ dwarfs and the nearest lowest–mass dwarfs, 2: surveys for $z > 6$ and KX quasars, 3: multiwavelength photometry of galaxies, 4: detection of cool stars with high proper motions (cool white dwarfs and Pop II brown dwarfs). Goal 4 is not part of the 2–year plan, obviously, since it relies on completion of the second stage of the LAS.

4.2 Science strategy

This section covers the principal science goals on timescales of two years, six months, and commissioning.

4.2.1 Two–year goals

The LAS was conceived as the infra–red counterpart to the Sloan survey, as well as an atlas for identification of sources detected in surveys at other wavelengths. Nevertheless, other than the statement that more is better, these aims do not at present provide a quantitative guide to choosing between say 1000 or $3000\square^\circ$ coverage in the first two years. Below we focus on the goals that set the scope of the two–year plan.

Rare objects. The LAS has the potential to achieve two very high profile results. These are the detection of the T+ sequence of very cool brown dwarfs, and the discovery of quasars at $z = 7$. Recent estimates by Nakajima suggest that over $2000\square^\circ$ we could expect between 10 and 100 T+ dwarfs. These numbers are very uncertain – which is one reason the survey will be so useful. We expect a handful of quasars of very–high redshift. If the SDSS provides the optical data we would find $5 - 6$ quasars in the redshift interval $5.8 < z < 7.2$.

If the $2000\square^\circ$ proposed here is imaged with the VST[1] to $z' = 21.5$ the situation is greatly improved. For example this allows the search for quasars to be extended from $Y = 19$ to $Y = 20$. Then the expected number of quasars in the higher redshift interval $6.4 < z < 7.2$ is between 7 and 9. This means that we can achieve two of the headline goals of the LAS in the first two years.

[1] Despite the destruction of the mirror during shipping at present the VST is still expected to start science operation early in 2004. It is the camera rather than the telescope which defines the critical path.

The LAS will also be useful for identifying the rarest brightest EROs. This population has proved difficult to characterise because the objects are so faint in the optical. The LAS would provide a bright sample suitable for detailed spectroscopic study.

Gravitational lenses and damped Lya galaxies. Using spectroscopy of bright $K < 16$ KX selected quasars from $2000\square^{\circ}$ we would expect to discover 250 DLA absorbers and 50 gravitational lenses. For reference current sample sizes from optical studies are approximately 100 and 50, but both samples suffer from biases due to dust that are not well quantified. Coverage of $2000\square^{\circ}$ produces new samples that either match or exceed the size of existing samples, selected at a wavelength where biases due to dust are greatly diminished.

4.2.2 6 month goals

Local galaxy studies. We have included $100\square^{\circ}$ centred on the Virgo galaxy cluster in the two–year plan. The essential argument is that we lose nothing by including Virgo – we can use this area for all the other LAS scientific goals – but that there is added value in observing this $100\square^{\circ}$ rather than some non–descript other $100\square^{\circ}$. The case for observing Virgo (as presented in the UKIDSS Science Case., Nov. 2001) is essentially the opportunity of exploring a large volume–limited sample of local galaxies in a high–density environment, down to very faint luminosities. In fact half of the area is included in the northern hemisphere block so we are merely adding on a $50\square^{\circ}$ extension to this block as follows: $12h11 < RA < 12h51$, $+10^{\circ} < dec < +15^{\circ}$ (Fig. 5).

A second 6 month goal is completion of the LAS portion of the SDSS deep stripe, between $20.7 < RA < 24h$, on the equator, which covers an area of $124\square^{\circ}$. This section of the SDSS will reach about 1.5 mag deeper than the main survey.

4.2.3 Commissioning

We propose $YJHK$ imaging of the Sloan $z > 6$ quasars and known L and T dwarfs. This will establish the sensitivities in the different bands, will confirm the strategy for selecting high–z quasars and T+ dwarfs, and could discover faint companion quasars at the same redshift. Coverage of known X–ray selected high–redshift galaxy clusters could be used to assess the effectiveness of LAS data for detecting distant galaxy clusters. Coverage of the Lockman hole region, where extensive redshift catalogues of AGN are available, would check the KX selection method.

4.3 Choice of fields

The combination of the imaging and spectroscopic data from SDSS, and the lack of comparable surveys, means that the entire LAS must be contained within the SDSS survey regions. Equatorial fields allow access from the VST and VLT. For these reasons the chosen fields are equatorial SDSS stripes $-10^{\circ} < dec < +15^{\circ}$, and all fields in this 2–year plan are accessible from Paranal. Fig. 5 indicates the locations of fields totaling $2575\square^{\circ}$. This area is greater than the requested $2000\square^{\circ}$. This provides some flexibility in the actual selection of fields dependent on the pressure from PATT requests at particular RAs. The main area is a block of

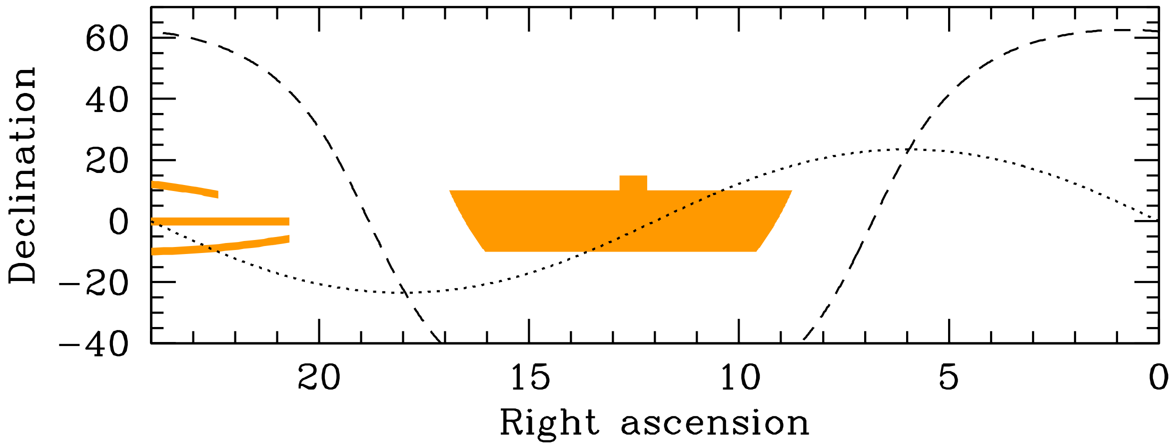

Figure 5: Locations of the LAS fields in the two-year plan. The thin stripes are the three SDSS stripes in the southern Galactic hemisphere. The protrusion on top of the northern block is the top half of the Virgo galaxy cluster field. The dashed line marks the Galactic plane and the dotted line marks the ecliptic plane.

area 2215□° in the northern Galactic hemisphere above Galactic latitude $b = 30°$ and between $-10° < \delta < +10°$ (covering the approximate range $9h15 < RA < 16h20$), plus a small protuberance of area 50□° which is the northern half of the Virgo field. This block includes most of the northern high–Galactic–latitude section of the CFH Legacy Survey ecliptic stripe which will have relatively deep i' and z' imaging. The remaining 310□° comprises the sections of the three SDSS stripes in the southern Galactic hemisphere within the range $20h40 < RA < 24h$. (The sections between $0h < RA < 4h$ are avoided as they clash with the UDS.) This includes the deep SDSS field which is the stripe at $\delta = 0°$, and which will reach some 1.5 mag deeper than the remainder of the SDSS survey. In summary, as requested by the Board, we have shifted the centre of gravity of the fields southwards, and increased the spread in RA.

4.4 Choice of filters

Goal 1, §4.1, relies on YJH photometry, goal 2 on YJK photometry, and goal 3 requires $YJHK$, of which J and K are the most useful. There is no sensible strategy which does not involve observing in all four filters. We propose approximately contemporaneous observations (within one lunation) in all filters in any field. This is because much of the science depends on selection by colour, but quasars and some cool stars are variable.

We recently completed a quantitative reappraisal of the Y band and the final choice of bandpass is 0.97 to 1.07μm (see also Warren and Hewett, 2002). The quantum efficiency of the first science array for WFCAM, quoted by Rockwell, is 68% in J. This is higher than expected. Until the quantum efficiency has been measured in the Y band it is not possible to confirm the efficiency of the Y survey, but the high quantum efficiency at J is an indication that the sensitivity assumptions around which the survey has been designed are conservative. Fortunately the WFCAM team plan to measure the q.e. of the first science array this year.

4.5 Seeing variations and non–photometric conditions

Because of the RA distribution of the DXS and UDS fields (which do not require photometric conditions) the LAS needs a strategy for non–photometric conditions, as explained in §3. Also because the fields are covered in a single observation a strategy for variable seeing is needed. Different possibilities were discussed within the consortium and the following solution is proposed.

Variable seeing: The LAS will be divided into three strips corresponding to three different seeing criteria i.e. excellent, average, poor (exact definitions to be decided). In poor conditions the integration time will be increased.

Non–photometric conditions: J band observations, with increased exposure time, of northern fields (outside the 2–year plan) will be made. These will act as the first epoch proper–motion data for these fields. The second epoch J, together with YHK, will be observed after an interval of 2+ years, in photometric conditions. For these later observations, in non–photometric conditions the second epoch J of the first 2–year plan fields could be observed.

4.6 Follow–up UIST and Michelle observations

The majority of the cool stars detected in the LAS will have magnitudes close to the survey magnitude limit i.e. $J > 19$. These are much fainter than stars successfully studied with UFTI and CGS4, so we expect the majority of the follow–up observations to be undertaken on 8m telescopes; VLT, Subaru, Gemini. Spectroscopy of the brighter sources could be undertaken with UIST. Photometry in the L' and M$'$ bands to define the long–wavelength SEDs of T+ dwarfs would be appropriate for UIST. Substantial demand for Michelle seems very unlikely although expanding the wavelength baseline of photometry of local galaxies is a possible science goal. We envisage a request for no more than 10 nights per year for LAS follow–up of cool stars using UKIRT.

4.7 Summary

The LAS 2–year plan is to observe 2000$\square^\circ$ close to the equator, and observable from Paranal, for 40s in YJHK. The area will be selected from the fields shown in Fig. 5, depending on scheduling constraints.

5 The UKIDSS Galactic Plane Survey Two Year Plan

5.1 Introduction

The Galactic Plane Survey (GPS) aims to survey the northern half of the Galactic plane in the JHK bands to K=19.0. The spatial resolution of 0.6 arcsec is 3 times better than 2MASS and will ensure that the survey is not confusion limited, except possibly close to the Galactic centre. The survey includes two repeat scans at K band to identify variability and measure proper motions over a period of several years. The field locations for the two-year plan are plotted in Fig. 6.

The principal science drivers remain those outlined in the full survey plan: (1) creation of a Legacy Database and 3–D Atlas; (2) study of Star Formation and the IMF with emphasis on environmental dependence; (3) counterparts to X–ray sources and High Energy Astrophysics; (4) AGB stars, PPN and Planetary Nebulae, including detection of brief phases of stellar evolution; (5) brown dwarfs: the GPS will have a similar detection rate to the LAS for very cool nearby objects.

5.2 Science Strategy

Inner Galaxy. The region of the inner galaxy which is close to the galactic plane ($|b| < 1°$) is given the highest priority. It contains most of the star forming regions and open clusters in the GPS. This region will naturally contain many other interesting stellar populations such as LMXBs, CVs and PPN. The $10 < l < 70$ area at $|b| < 1$ (RA=19 hours) will be observed in GLIMPSE, the public SIRTF Legacy programme at 3–10 μm led by Ed Churchwell at U.Wisconsin. Overlap with GLIMPSE has been identified as a top priority by the UKIRT Board. The region also includes many of the relevant radio surveys, eg. the BU–FCRAO Survey (Law et al. 2000). The previously planned GPS region in the inner galaxy was latitude $|b| < 5$ and longitudes $15 < l < 107$, being limited to Dec., $\delta > -15°$. A southern extension to this is now proposed: $-2 < l < 15$ in a narrow strip at $|b| < 2$. The southern extension is a response to important recent discoveries of hundreds of SNe remnants, compact objects and other sources close to the galactic centre in the X–ray and radio wavebands (Wang et al.2002; Hasegawa et al. 1998) and major new IR results from DENIS on the structure of the inner galaxy as 'a typical ring–barred spiral' (Lopez–Corredoira et al. 2001).

Greater southern coverage is also desirable for new practical reasons: desire for follow–up with ESO facilities, overlap with optical ESO public surveys and anticipated competition from the CFHT–WIRCAM, which is likely to be in operation before VISTA. Hence, JHK observation of the ESO optical Pre–FLAMES survey fields in the Bulge are proposed, and a sparsely tiled vertical column extending into the Bulge in addition. These observations will be very fast with WFCAM (a few hours total) and will provide the first statistical data on the Bulge stellar population below the main sequence turn–off. These Bulge observations were requested by members of the ESO public surveys committee, and are included despite their brevity because of the need for ESO–wide availability and advertisement of the dataset.

Main Survey. In addition we wish to begin two representative blocks of the survey with the full $|b| < 5$ thickness in the inner and outer galaxy (summer and winter respectively) in order to begin addressing the goals summarised in the Introduction. The precise size of these blocks is arbitrary so we propose to observe a survey area which brings the total time request up to the level proportionate to the fraction of all UKIDSS time that has been allocated to the GPS. Assuming 290 nights are avialable to UKIDSS in the first 2 years, that level is $186/946 \times 290 = 57$ nights.

Data in the $1 < |b| < 5$ region is needed to cover 3 important regions: (1) the Thin Disk at heliocentric distances $1.1 < d < 5.2$ kpc, up to 1 scale height ($h \approx 90$ pc). (2) Galactocentric radii $R > 1.5\ R_{\odot}$, where the disk becomes significantly warped. (3) the Thick Disk and its evolved populations ($h \approx 400$ pc).

5.2.1 Two-year goals

The stellar IMF will be measured in several dozen young clusters and star forming regions in different environments. This will reveal the major environmental influences of star formation, which present statistics are inadequate to show (Kroupa 2002). The apparently more variable substellar IMF will also be measured in many star forming regions within 1 kpc, eg. the Z CMa association.

A large sample of new YSOs will be identified in the SIRTF–GLIMPSE region. Evolution of the protoplanetary disks will be addressed in well defined samples of T Tauri stars and Herbig Ae/Be stars using $1 - 8\mu$m WFCAM and SIRTF photometry.

The counterparts to the X–ray XMM Galactic Plane Survey fields observed by the end of 2005 will be detected. This XMM/UKIRT dataset will yield the first clear X–ray view of the Galaxy, with the IR data distinguishing the large populations of YSOs, CVs, Active Stars, and the smaller population of LMXBs and HMXBs. Several thousand sources will be detected.

Of order 10 ultracool (T+) brown dwarfs will be detected in the Solar Neighbourhood at 400–800 K (requiring spectroscopic confirmation). This is a major goal of the LAS but it should be noted that the same science will also be rapidly produced by the GPS. Note that the Y filter is not needed since high extinction distinguishes distant contaminating OBAF–type stars.

Galactic Centre and Bulge Science is covered above.

The 1st pass of the H_2 survey in the Taurus–Auriga–Perseus (T–A–P) star formation complex will identify all the brighter macrojets and smaller jets in the region, permitting a major statistical analysis of outflow frequency and size as a function of the age of the YSO. Jet continuity or lack of it will test the idea of episodic accretion and ejection. The first of three epochs must be done early to measure proper motions. The Board have indicated that they rank the H_2 survey below broad-band imaging, and for this reason we propose that the first H_2 observations will be undertaken in year two of the two-year plan.

5.2.2 6 month goals

This is dependent on commissioning date. The Galactic Centre science on X–ray and radio counterparts and the study of the main sequence population in the Bulge may be completed. With the exception of commissioning science the other science returns will require two years.

5.2.3 Commissioning

A single tile around the Galactic Centre will identify the IR counterparts to hundreds of X–ray and radio sources: SNe, AGB stars, LMXBs etc. Not suitable for November 2003 commissioning, but observable if commissioning is delayed until April 2004.

The first IR mapping of two macrojets in H_2 + K, probably in Taurus, would be suitable for winter 2003 commissioning. This may yield Nature quality science on accretion and outflow history over 10^5 yr. Images of a degree–scale jet will also generate publicity for UKIRT and WFCAM, informing the astronomical community that wide field IR astronomy has arrived. This requires 1 deep H_2+K tile of 1800 s duration per object.

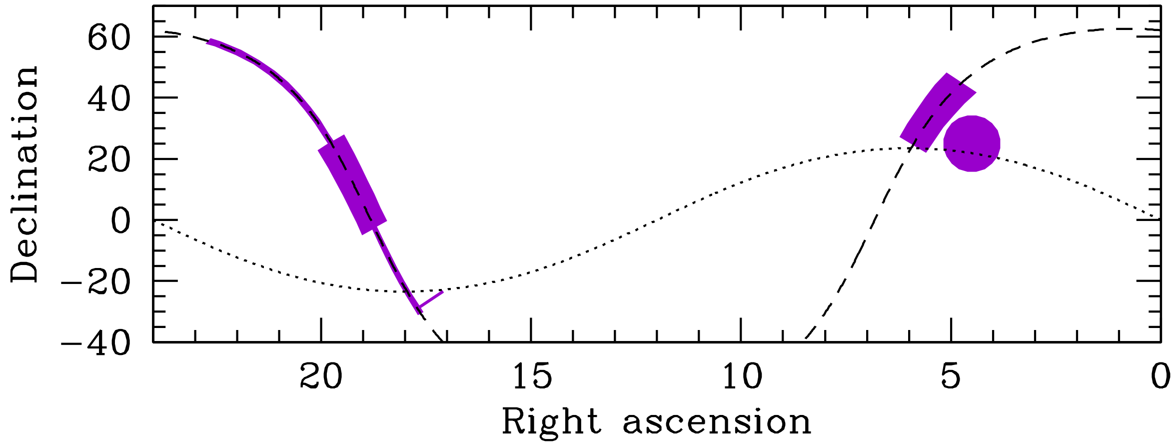

Figure 6: Locations of the fields in the two–year plan. The dashed line marks the Galactic plane. The thin stripe is the section of the galactic plane to be covered between $-1 < b < +1$. There are two patches to be covered between $-5 < b < +5$. Finally the circular patch indicates the Taurus–Auriga–Perseus region which will be imaged in the H_2 line. The dotted line marks the ecliptic plane.

5.3 Choice of Fields

The target fields in the first 2 years are shown in Fig. 6 and are the following:

(i) $-2 < l < 107$ at $|b| < 1$. This consists of the SIRTF GLIMPSE region, the southern extension to $l = -2$ and rest of the 'inner galaxy' up to $l = 107$. These regions contain the highest density of star formation regions, young clusters and X–ray binaries. The observed strip will in fact be nearly 2.5° thick as it will be made up of three tiles. This is accounted for in the time calculation, and the summary in Table 2. The area near the galactic centre ($\delta = -28°$) will be observed at airmasses of 1.45 to 1.65. The remainder of the southern extension at $1 < |b| < 2$ will be done later.

(ii) Two $|b| < 5$ blocks of the GPS (summer and winter). One block should be at $30 < l < 62$, covering the region at $1 < |b| < 5$. This will probe the 5 kpc ring of intense star formation.

Another could be at $160 < l < 185$ and $|b| < 5$. The choice of longitude in the outer galaxy is not critical and could be chosen to avoid conflict with the other surveys in the first 2 years and improve observing efficiency.

(iii) Any XMM–GPS fields not included in (i) and (ii). These will cover only a small area (< 1 night).

(iv) The ESO Pre–FLAMES Bulge fields and the vertical bulge strip. This will take 0.5 nights at airmass 1.45 to 1.65.

(v) The 1st pass of the H_2 survey in the Taurus–Auriga–Perseus complex (marked as the large circle in Fig. 6), to be done at the same time as the GCS K band imaging of the same region late in year 2. This region will be done in year 2.

The time required for the different elements is summarised below:

Time Summary for the Two Year Plan

Target	RA	Time Required
GLIMPSE+ : $-2 < l < 107$, $\|b\| < 1$	18-23h	14.4 N
XMM–GPS Fields	18–20h	~ 1 N
ESO Bulge & Vertical Strip	18h	0.5 N
GPS Inner Galaxy Block	18–20h	15 N
GPS Outer Galaxy Block	3.5–7.5h	15 N
T–A–P H_2 1st Pass	3.5–5.5h	11.3 N
Total		~ 57 N

5.4 Choice of Filters

The GPS consists of a main scan at JHK, and two follow–up scans at K band only to detect variability and measure proper motions. The JHK scan will be done first, since this is essential for source identification, dereddening, detection of K band excesses in YSOs and for luminosity and distance measurements. Note that accurate distances will be obtained for clusters but will not be reliable for all individual stars. Some of the K band follow–up data may be taken early if they can be done in non–photometric conditions.

5.5 Seeing variations and non–photometric conditions

Seeing: the GPS is not quite confusion limited K=19.0 for $l > 40$ in median seeing. However we anticipate that median seeing of 0.6 arcsec will be desired for $-2 < l < 70$ and $|b| < 2$ since confusion will occur in poor seeing. At large longitudes this requirement can be slightly relaxed (further UFTI data are being obtained to quantify this), but the desire for proper motion measurements (primarily for white and brown dwarfs) means that a seeing limit of 0.8 arcsec is desired, at least for the K band data. In practise the limit applies to the J and H data also, since it is preferable to make JHK observations of each field consecutively.

Non–photometric conditions: The K–band only scans may be attempted in non–photometric conditions, with exposures times increased to compensate for reduced throughput. There will be many sources in each array field, so the variability data can be recovered by bootstrapping average zero–points from one of the other scans, provided that cloud does not cause the throughput to vary with high spatial frequency across the array.

5.6 Follow–up UIST and Michelle Observations

UIST and Michelle will be the principal instruments for photometric and spectroscopic follow–up: confirming and characterising YSO candidates, accretion disks around compact objects, circumstellar matter associated with AGB stars/PNe and study of ultracool brown dwarfs. There is likely to be a large number of PATT applications each semester requesting up to say 30 nights per semester. Given the diversity of GPS science it is difficult to quantify the need for rapid follow–up on timescales faster then the normal PATT process: perhaps 3 nights/semester would be suitable to follow up H_2 commissioning data and brown dwarf candidates etc.

6 The UKIDSS Galactic Clusters Survey Two Year Plan

6.1 Introduction

The GCS will cover 1400 □° in JHK to K=18.7, requiring 74 nights[2]. The nominal proportional allocation for the first two years is 26 nights, and the consortium proposal is for 30 nights. The GCS comprises observations of 10 clusters and star formation regions; K band observations will be done twice with as large an epoch separation as possible for the measurement of proper motions. The GCS 2–year plan is based on a prioritisation of the 10 targets from consideration of scientific impact of single–epoch imaging and the need to establish early–epoch K band imaging for the survey as a whole. The field locations are plotted in Fig. 7.

A key science goal of the GCS is the form of the MF in the substellar régime and thereby a measurement of the contribution to the total mass in stellar systems made by brown dwarfs (BDs). As illustrated in Figure 4.1 in the GCS section of the UKIDSS case, at $m = 10$ $\mathrm{M_{Jupiter}}$ the number of stars per unit mass is currently uncertain by more than an order of magnitude. Equally important is the question of the universality (or dependence on environment) of the IMF in the BD régime. The GCS 2–year plan provides a quick science return: lists of candidate BDs in the richest cluster environments and initial estimates of the form of the MF therein. It will also provide an initial analysis of the variation in the form of the IMF.

6.2 Science strategy

The GCS science requirements necessitate early observations (in K band at least) for the targets in order to provide first epoch positions for eventual proper motion measurement. However, to enable quick exploitation, early follow–up and preliminary science results, we suggest three colour imaging in as large an area as possible in all targets. The GCS target list comprised 9% of all UKIDSS time in the revised science case (84n out of 946n). Working with these numbers, proportionately the GCS should therefore use around 26n in 2 years if the total UKIDSS allocation over that period is 290n. At their meeting in April 2002 the Consortium recognised the high ranking attached to the GCS by the Board, and the relatively small number of nights required for the survey. Consequently the Consortium appreciated the value of only a small increase in the number of nights to be allocated to the GCS in the two–year plan as this would substantially increase the fractional completion of the survey. The final agreed figure was 30n. Using efficiency figures from the UKIDSS proposal, it takes one average night to survey 76.2 □° in one waveband. Based on this figure our proposed strategy for the first 2 years is as follows: i) all targets will be imaged at K band only (requires 18.4 nights); ii) all open clusters except Hyades and Coma–Ber will additionally be observed at JH (4.1n); iii) the central half of the Hyades area will be imaged at JH (146 □°, 3.8n); iv) the remaining 3.7n will be used to image the central parts of the star formation regions in JH.

The two-year plan is summarised in Table 4 which is ordered by target priority.

Priority for the clusters is set by the minimum mass achievable modulo the cluster richness; clusters have priority over the star formation regions as requested by the Board. For immediate

[2]These figures are revised from the original plan of 1600□° requiring 84 nights, because of the revision of the target list after a search for suitable southern clusters.

Relative priority	Target	Bands/areas (filters/sq.deg)	Time (nights)
1	Pleiades	JHK/79	3.11
2	Alpha Per	JHK/50	1.97
3	Praesepe	JHK/28	1.10
4	IC 4665	JHK/0.8	0.03
5	Taurus–Auriga	JHK/central 47	1.75
6	Orion	JHK/central 47	1.75
7	Sco	JHK/central 47	1.75
8	Per–OB2	JHK/12.6	0.50
9	Hyades	JHK/central 146	5.73
10	Hyades	K only/remaining 146	1.92
11	Coma–Ber	K only/78.5	1.03
12	Taurus–Auriga	K only/remaining 339	4.45
13	Sco	K only/remaining 107	1.40
14	Orion	K only/remaining 267.2	3.51
		Total:	30.00

Table 4: The two-year plan for the GCS. In practice, any given pointing for the GCS will be observed at JHK together or K only at one or other of the two epochs. The observations are listed in order of priority.

positive results, we lower the priority of the associations for which there is evidence of a paucity of low mass/substellar members (Hyades, Coma–Ber, Perseus) but of course one of the ultimate GCS goals is an examination of the universality (or otherwise) of the stellar IMF; the survey as a whole (i.e. the full $\sim$ 6yr UKIDSS GCS programme) is not biased against associations where the IMF may be different.

The resulting principal science goals over the 2 year period are then as follows.

6.2.1 Two-year plan

To derive preliminary mass functions in the central areas of the star formation regions in order to yield an initial analysis of the dependence of the IMF on environment from the homogeneous GCS survey data; additionally to provide lists of candidate BDs in the SFRs.

6.2.2 6 month plan

To derive preliminary mass functions in all targeted open clusters and provide lists of candidate BDs therein.

6.2.3 Commissioning

To derive a preliminary mass function for as much of the Pleiades area as possible and to provide a list of candidate BDs for follow–up work. The goal would be to complete the entire Pleiades field, which requires three nights, and would provide a striking early result for UKIDSS.

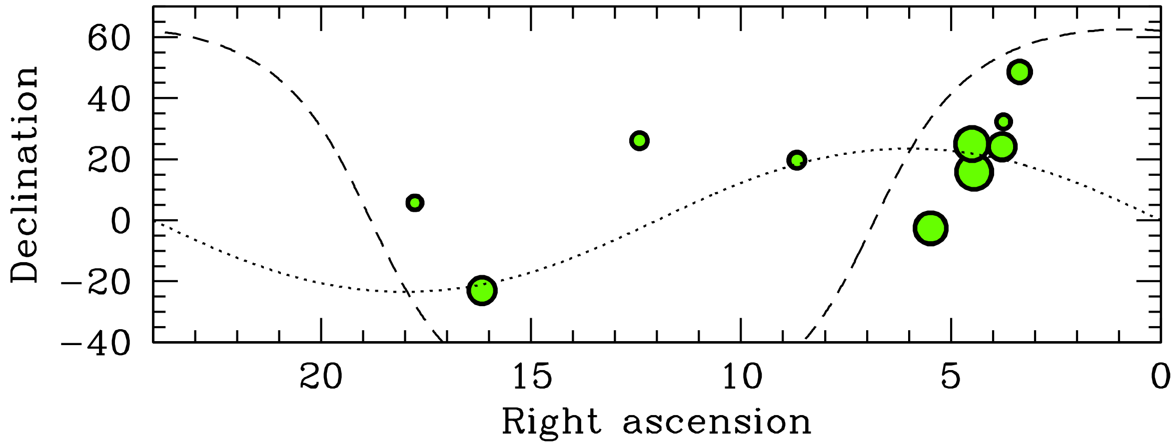

Figure 7: Locations of the fields in the two–year plan. The size of the symbol is representative of the time requested for that field. The dashed line marks the Galactic plane and the dotted line marks the ecliptic plane.

6.3 Choice of fields

The GCS target list has been updated in the light of the UK entry into ESO and a thorough literature review. There are 10 target open clusters and star formation associations. Full details can be found in
`ftp://ftp.roe.ac.uk/pub/nch/UKIDSS/table.ps.gz` The target locations are plotted in Fig. 7.

For the cluster targets, field centres have been computed using 5% overlaps and priorities set on the basis of proximity to the nominal cluster centre. Figure 8 shows an example for IC 4665, where the crosses indicate the centres of each pointing and star symbols are Tycho catalogue bright stars. Similar plots are available for all targets at `ftp://ftp.roe.ac.uk/pub/nch/UKIDSS/*.gif`. Note that the Hyades overlaps with the Pleiades and the Taurus–Auriga area is non–circular with overlap areas in the Hyades, Pleiades and Per–OB2 excluded. Overlap areas between Coma–Ber and the LAS and Alpha–Per and the GPS still need to be taken into account in the final survey design.

Cluster 'centres' and 'extents' are less well defined for the star formation regions. We have specified areas and prioritised on proximity to the co–ordinates listed in Table referenced above based on the following considerations: Per–OB2 – de Zeeuw et al. (1999), esp. Fig. 17; Taurus–Auriga – Ungerecht & Thaddeus (1987) esp. Fig. 4, Gomez et al. (1993) esp. Fig. 8 plus some

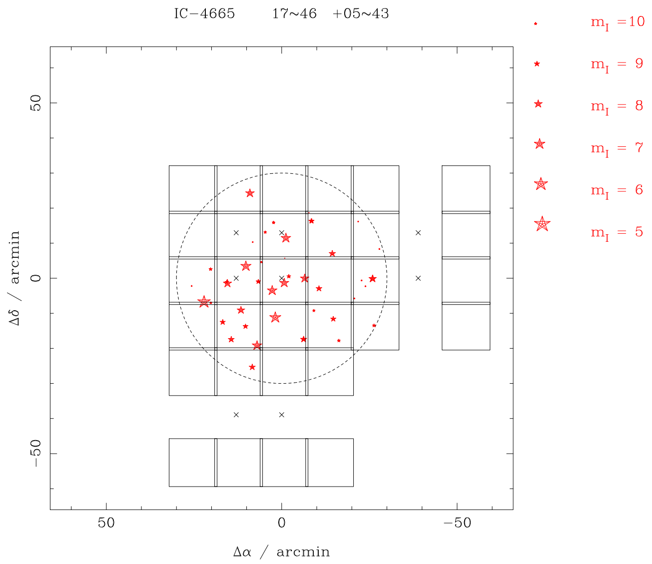

Figure 8: Example GCS pointings: IC 4665 (see text).

current work of our own in this region; Orion – priority is based on proximity to the σ–Orionis and Trapezium clusters; Sco – we take as priority the Upper Scorpius part of Sco–OB2 (de Zeeuw et al. 1999 esp. Figs. 6 & 9; see also Ardila et al. 2000, esp. Fig. 1). Prioritised lists of field pointings for all targets are available at `ftp://ftp.roe.ac.uk/pub/nch/UKIDSS/*.lis`. The columns in these files are: relative priority, RA & Dec (J2000.0), distance from nominal centre.

6.4 Choice of filters

The GCS requires three–colour IR photometry for the purposes of selecting candidate BDs. We do not require Y band observations; recent work on the field BD population (Dahn et al., astro–ph/0205050) shows that (I–J) is the best temperature indicator. Near–infrared (IZ) observations for all UKIDSS fields south of $+25°$ will be routinely obtained via ESO imaging programmes with WFI/2.2m or VST. Many fields north of this limit are to be observed as part of other survey programmes (e.g. CFHT cluster surveys) and the data will be publicly available after short proprietorial periods.

6.5 Seeing variations and non–photometric conditions

Variable seeing: The astrometric (K band) imaging for the GCS needs to be obtained under conditions of median (or better) seeing. Under poorer seeing (but photometric) conditions, JH observations will be obtained.

Non–photometric conditions: Under good seeing, but non–photometric, conditions K band observations for astrometry only will be obtained. Under stable, non–photometric conditions, we propose that the 5% overlap regions between adjacent fields can be used to bootstrap photometry provided that a chequered pattern of observations is adopted, whereby gaps are left in the contiguous survey regions to be filled in later under photometric conditions.

6.6 Follow–up UIST and Michelle observations

As with the LAS, the majority of the BDs detected in the GCS will have magnitudes approaching the survey limits so we expect the majority of the follow–up observations to be undertaken on 8m telescopes. Spectroscopy of the brighter sources could be undertaken with UIST. We do not expect any significant demand for Michelle. Although hundreds of BDs will be discovered, we expect a combination of near–infrared and infrared photometry and proper motions to be used primarily to establish cluster membership. Small–scale programmes of spectroscopic follow–up of subsamples of BDs in the clusters will likely be undertaken. We envisage requests of no more than 5n per semester for follow–up of GCS BDs using UKIRT.

6.7 Summary

The GCS 2–year plan is: i) make quick returns on the rich open cluster targets within the GCS list and provide lists of candidate BDs; ii) establish first epoch K band imaging for all targets to enable proper motion determination after a second epoch pass; iii) provide a first analysis of the variation of the IMF over the cluster/association targets. The priority for observations is strictly as given in Table 4.

7 The UKIDSS Deep Extragalactic Survey Two Year Plan

7.1 Introduction

The UKIDSS Deep Extragalactic Survey (DXS) aims to reach a 5σ point–source sensitivity of J=22.5 and K=21 over an area of 35□° to focus on the Universe at redshifts of 1–2 selecting galaxies in the rest–frame optical band. The major science goals of the DXS hinge on the availability of high quality data from other wavelengths (optical, far–IR, radio, UV, X–ray, etc.) to identify passive, star–forming and active galaxies within the same volume at a redshift where star–formation and nuclear activity are believed to be most prevalent. The majority of the complementary datasets are yet to be observed but all will be started and several finished (e.g. SWIRE with SIRTF) by the time the first DXS data become available to UK and European astronomers. Many others will be available within the first two years of UKIDSS and all of the relevant surveys will be complete by the end of the fifth year of the Survey. The field locations are plotted in Fig. 9.

7.2 Science strategy

The scope of the DXS in terms of area (tens of square degrees), redshift coverage ($1 < z < 2$) and number of sources (order 10^{6-7}) is similar to several other projects at different wavelengths. These include: the CFHT Legacy Survey (CFHLS), the SWIRE survey with SIRTF, the Deep GALEX survey, the XMM–LSS survey, as well as (in terms of area and redshift coverage) the AMI S–Z wide–area survey. In other words the DXS is part of an international multi-wavelength effort to study the Universe at these redshifts on scales of tens of Mpc. The principal science goals of the DXS – the abundance of galaxy clusters at high redshift, and the evolution of large–scale structure – require completion for the full value of the DXS to be realised. The other main goal, the multi–wavelength census of the luminosity density in star formation and AGN – can be mostly achieved within the two–year plan. With this in mind the basic strategy of the DXS is to complete a substantial fraction of the survey area to full depth, rather than complete the whole area to shallow depth, focusing on the regions which will have the best completed multi–wavelength coverage by the end of 2005.

The fact that only one DXS field will be visible at any one time means there is no need to prioritise fields within the DXS. However, the relative priority of each field against the other surveys (e.g. XMM–LSS against the UDS and the Lockman Hole against the LAS) can be used to increase the chances of one field being done before the other. Given the priorities expressed by those in UKIDSS and the seeing/transparency demands of the respective surveys then the XMM–LSS field is likely to be favoured (the need for the best seeing in the UDS increases the time available to the DXS).

The experience gained in the first two years in the relative scheduling against other surveys will be used to derive the final area split between the four DXS fields. There is no strong scientific motivation to have four fields of exactly the same size so we have a flexibility to use time when it is available as long as a minimum area is covered in each DXS field (say 10 'tiles' or 7.5□°). This will require a margin in the optical data but in the latter stages of the survey this should not be a serious hurdle and the planned surveys such as CFHLS are significantly larger than the DXS fields.

7.2.1 Two–year goals

The two–year goal of the DXS is to complete a substantial fraction of the area to full depth in J and K, 12.6□°. As listed in Table 2 the proposed fraction is 36%. This makes sense in terms of determining parameters (e.g. cosmological parameters from the abundance of galaxy clusters) since it implies achieving more than 50% of the final goal i.e. the final errors will only shrink by a factor $1/\sqrt{0.36} = 1.7$. Over this area the estimated number of SWIRE sources of different types is 2×10^4 starbursts, 2×10^5 ellipticals, 5000 classical AGN, and 4×10^4 obscured AGN.

7.2.2 6 month goals

Our 6 month goal is to complete a contiguous area of at least 1 deg^2 to full depth in J and K in one of the two northern fields, and a similar area in one of the two southern fields. This will allow detailed work comparing the detectability of high–redshift clusters at X–ray, optical/near–ir, and S–Z wavelengths. This will also be enough to establish the ERO counts, and provide identifications for thousands of SIRTF sources.

7.2.3 Commissioning

There are no quick science goals of the DXS that can be realistically completed in commissioning. However it would be useful for a deep tile in one band in one of the fields to be completed in order that we can experiment with an optimal strategy for stacking WFCAM data. It would also be extremely useful to use this time to compare different dithering strategies. This is a topic currently under consideration and we expect to put forward more concrete proposals in due course.

7.3 Choice of filters

The DXS science case requests J and K for the full area for the best photometric coverage with a small (≈ 5□°) sub–area covered in H. For the initial two years observations will be restricted to J and K (H can be added later to completed 'tiles' where demand from other surveys is light). Performing all observations in K has been suggested, and we wish to reserve this as an option pending further modelling of the usefulness of $K - SWIRE$ colours. However it would limit our ability to differentiate between EROs which are passively evolving or very dusty through J–K colour. The current proposal, therefore, is to complete a fraction of the area of the DXS to full depth in J and H. The high measured q.e. in J of the first science–grade array indicates that the J exposures might be reduced (i.e. saving time), or instead we could use the same time to go deeper. We certainly prefer the latter option as it allows the survey to detect ellipticals at higher redshifts than the current goal $z = 1.5$. This is particularly valuable for comparison with the AMI S–Z searches for high–redshift galaxy clusters.

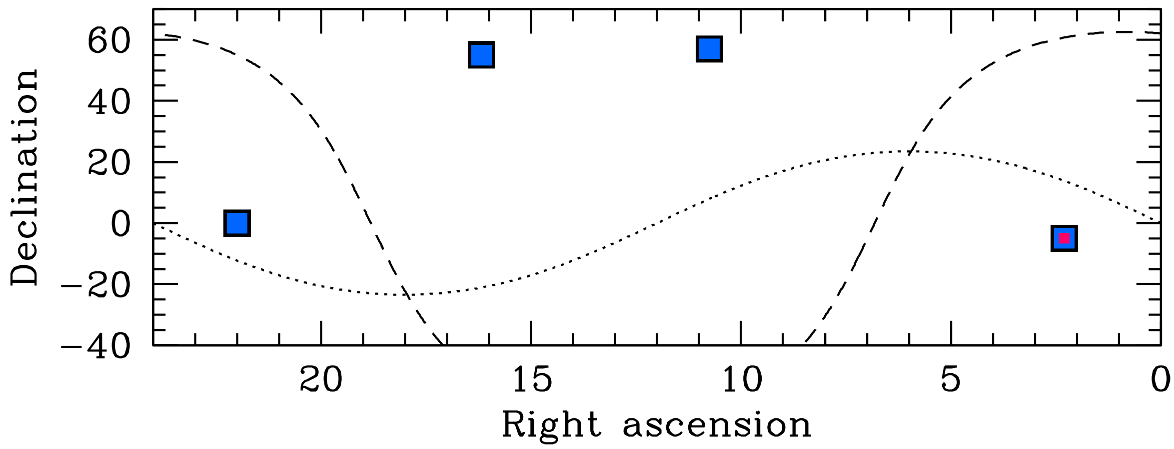

Figure 9: Locations of the DXS and UDS fields in the two–year plan. The blue squares mark the four chosen DXS fields. The small cherry–coloured square inside the blue square at J0218–05 marks the location of the UDS field. The dashed line marks the Galactic plane and the dotted line marks the ecliptic plane.

7.4 Choice of fields

The original DXS case envisaged three fields, allowing statistical comparison of the scientific results between fields. The ability to sample structures of 100–200 Mpc at redshifts of 1–2 requires a minimum field area of 7.5□° (i.e. 10 WFCAM 'tiles'). The area approved of 35□° limits us to a maximum of four fields if the minimum field area constraint is enforced.

The final choice of fields is a consequence of balancing two strong opposing forces. To the south there is the new opportunity for deep spectroscopy with the VLT. To the north a fruitful synergy between UKIDSS and the AMI S–Z group at Cambridge is developing that is focused on the primary goal of the DXS, the evolution of the abundance of galxay clusters. The DXS requires fields covering a few to several square degrees with existing or planned multiwavelength coverage, and low cirrus. Optimising these requirements has led us to the final choice of the following four fields:

- **XMM–LSS** – 2hr–05deg – full multi–wavelength coverage and surrounds UDS field
- **Lockman Hole** – 11hr+57deg – full multi–wavelength coverage, covers SCUBA Deep Field and ultra–deep VLA imaging
- **ELAIS N1** – 16hr+57deg – full multi–wavelength coverage
- **VIMOS–4** – 22hr+00 – requires VST imaging

The field locations are plotted in Fig. 9. The fields are approximately uniformly spaced in RA, which is good from the point of view of scheduling. The choice of the two northern fields is optimal for a coordinated 'blind' Sunyaev–Zel'dovich Effect survey with the Arcminute Microwave Imager (AMI) as the declination of Cambridge allows very efficient observing of two fields of similar, high declination. The AMI survey will cover a few tens of square degrees over a five year timescale and detect 50–200 clusters beyond a redshift of one that will require deep NIR imaging for identification. The second equatorial field is the only field that requires dedicated optical imaging. The availability of VST and the strong support shown from ESO for equatorial surveys will mean that obtaining the optical data for this field will not be a major obstacle.

7.5 Seeing variations and non–photometric conditions

Photometric conditions are not required for the DXS. In addition the image quality requirements are not quite as restrictive as for the UDS (since the redshift limit is lower). Under these circumstances it does not seem realistic to impose restrictions on observing conditions for the DXS. The stacking procedure will optimise the final frame to account for the varying conditions. Nevertheless it is a requirement that the coverage in each band across the DXS fields be as uniform as possible, in terms of depth and image quality. Therefore depending on the history of observing conditions in each patch of each field, we will want to target particular patches appropriate to the observing conditions e.g. to compensate for poor seeing conditions for that patch.

7.6 Follow-up UIST and Michelle observations

The depth of the DXS results in the vast majority of the objects detected being much fainter than the practical spectroscopic limit of UIST so the scope for UKIRT follow–up is very limited.

7.7 Summary

The DXS is one of the more flexible elements of the UKIDSS survey and complements the requirements of the other sub–surveys. The DXS requires no 'pump–priming' in the initial phases and will have a significant science impact from the point the first 'tile' is completed.

8 The UKIDSS Ultra Deep Survey Two Year Plan

8.1 Introduction

The Ultradeep Survey (UDS) is the deepest UKIDSS Survey, aiming to reach 5σ point–source depths of K=23, H=24 and J=25 over an unprecedented $0.77\,\square^\circ$ field. The field chosen is the Subaru/XMM Deep Survey field at J0218–05. The field location is plotted in Fig. 9.

In this report we outline the plans for the first two years of this survey. Our recommendation is to go deep as quickly as possible and complete the K–band imaging to $K \simeq 23$. This will not only enable us to answer many of the key science drivers behind this survey (e.g. the number counts and angular clustering for faint EROs) but will also be ideal for the identification of sources found in the sub–mm, FIR, radio and X–ray surveys of this field. We strongly argue for contiguous coverage, since a single disjoint tiling will severely compromise the usefulness of UDS for other multiwavelength surveys in this field.

8.2 Science strategy

Given that we are observing a single field, the choices open to the UKIDSS consortium regarding UDS are somewhat different to the other surveys. Rather than choosing our top priority fields we must decide between area, depth and J, H, K coverage. This section covers the UDS two–year goals. Given the long–nature of the UDS science goals we have not specified any 6 month or commissioning goals. Nevertheless the suggestions for commissioning observations for the DXS, relating to stacking and dithering, are also helpful to the UDS.

8.2.1 Area – a contiguous field or a single WFCAM tile?

A previous recommendation of the UKIRT Board was to reduce the area of the UDS from a contiguous, 0.8 sq deg field to a single tile (thus reducing the time required by a factor of 4). However this will severely compromise an important goal of this survey, namely to measure the clustering amplitude of the various populations. This requires a contiguous area in order to probe > 20 comoving Mpc and thus probe the linear regime for the growth of structure.

Most importantly, however, incomplete coverage would severely damage the usefulness of UKIDSS for the suite of other deep surveys being conducted in this field (e.g. in the X–ray, sub–mm, mm, optical, radio and FIR: see below). As a service to the broader UK/ESO communities we therefore strongly recommend contiguous WFCAM coverage.

8.2.2 Depth vs. J,H,K coverage

Should we go very deep in one band, e.g. the K–band, or build up depth gradually in all bands over the lifetime of the survey? The UDS team strongly support the strategy of completing the K imaging first. This can be achieved within year 1 ($\sim$ 40 nights). There are pros and cons to both approaches, but on balance we argue for completing the K–band imaging over 0.8 sq deg as quickly as possible.

Complementing the other surveys in this field

Given the exceptionally deep U, B, V, R, I, z' coverage that we anticipate from VLT and Subaru, a strong argument could be made for obtaining very deep complementary K–band imaging as quickly as possible to give the broadest possible wavelength range for photometric redshift determination in this uniquely studied field. In addition, very deep K–band imaging would be the most efficient way to obtain counterparts for the sources detected in this region at other wavelengths. Many of the most interesting X–ray, SIRTF and sub–mm sources are predicted to be EROs. With Subaru imaging to $R = 28, I = 27$, depths of $K = 23$ would enable all the EROs ($I - K > 4$) to be identified to complementary depths. A large fraction of the sub–mm sources in particular are likely to be invisible at optical wavelengths and will require K–band imaging to the greatest depths possible. Identifying these populations in the K–band will then enable more efficient follow–up work on 8–m class telescopes.

Influence on the primary scientific aims of UDS

The primary scientific goal of UDS is to determine the abundance of high redshift elliptical galaxies, providing a fundamental test for galaxy formation theories. Achieving this goal will require the full depth and area of the 5–year survey, but below we discuss what can be achieved within 2 years given the various options for UDS.

Within 2 years it will be possible to complete the K–band imaging to a depth of $K = 23$ and begin the J, H imaging. Combined with deep optical imaging from Subaru, particularly I–band imaging to $I = 27$, we can then readily identify all the elliptical galaxies at $z > 1$. We anticipate that the resulting deep ERO counts alone will provide a tight constraint on the evolution of high–z massive galaxies (see Roche et al. 2002). The addition of J, H colours in subsequent years will then provide reliable photometric redshifts and a much tighter discriminant between old passive systems and dust reddened starbursts.

Another major aim is to measure the clustering of galaxies at $z = 3$. With a combination of deep optical and IR imaging we will obtain the first large–volume map of the high redshift Universe. The optical VLT and Subaru imaging (U,B,R,I,z') will enable the Lyman–break objects to be readily identified. Deep K–band WFCAM imaging will provide a wider baseline for photometric redshifts and enable a more accurate segregation by galaxy mass. Crucially, WFCAM will enable all the EROs ($I - K > 4$) to be identified to the limiting depth of the Subaru imaging ($R = 28, I = 27$).

Publicity

While the 2–year plan for UDS should be made on scientific grounds, completing our K–band imaging to $K = 23$ (which is feasible within year one) would provide a major publicity coup for UKIDSS and WFCAM. An image to this area and depth would be unique, and a factor of ~ 1000 larger than any other survey to this depth.

Proposal

On the basis of the above the main goal of the two-year plan for the UDS is to complete the K–band imaging over the full area, which requires 39 nights. The second most useful band is J, where the final depth will be $J = 25.0$. A realistic goal, then, for the two-year plan is to reach for $J = 24.0$, which requires an additional 22 nights. At the April meeting of the consortium an allocation to the UDS of 62 nights was proposed, which is just enough to achieve these two

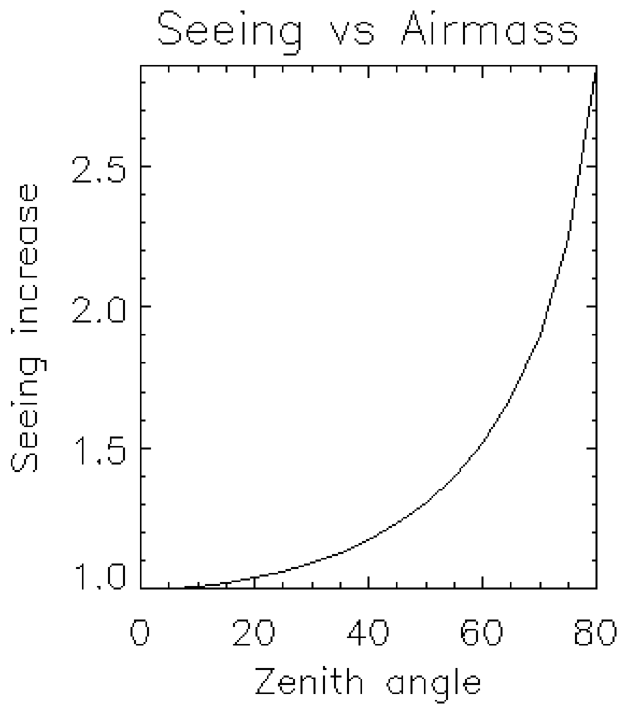

Figure 10: Proportional increase of seeing with zenith angle in the K band.

goals.

8.3 Seeing variations and non–photometric conditions

As for the DXS the UDS does not require photometric conditions.

The need for good seeing for in the deepest UKIDSS field is arguably self–evident. Although seeing affects the observational efficiency equally for all background limited surveys, for the deepest UKIDSS survey (particularly for a single field) it would be perverse not to optimise the image quality and depth. Good seeing is also strongly required by the science goals. One aim is to determine the Kormendy relation for high–z elliptical galaxies as a strong test of their evolution, which requires accurate measurements of their half–light radii. An L^* elliptical galaxy at $z > 2$, for example, will have a half–light radius of ~ 0.5 arcsec. In addition, while we anticipate a full–aperture magnitude of $K \simeq 21 - 22$ for L_* elliptical galaxies at $z = 3$, a crucial test of their formation will be to determine whether these are forming from smaller sub–clumps, which requires optimal seeing and point–source depth.

With the above considerations in mind we request that the UDS is observed only when the seeing is better than 0.7 arcsec. This corresponds to the best 70% of the seeing according to the latest UKIRT figures (UKIRT Newsletter Issue 10). This will place constraints on the airmass of observation since the seeing degrades with airmass (roughly as airmass$^{0.6}$.

This requirement is slightly at variance with the results of the scheduling study summarised in §3, but not by much. The analysis there indicated that in scheduling the UDS observations it would be difficult to reject more than the 20% worst seeing, compared to the 30% requested here. This further underscores the desirability of scheduling WFCAM more frequently during the months the UDS field is visible.

8.4 Follow-up UIST and Michelle observations

The depth of the UDS results in the vast majority of the objects detected being much fainter than the practical spectroscopic limit of UIST and we do not envisage follow–up observations of the UDS with the other UKIRT instruments.

8.5 Progress so far: the accumulation of multiwavelength data

The Subaru/XMM Deep Survey (SXDS) field at J0218–05 has already been chosen as the location for this survey. Here we summarise the accumulating multiwavelength data, including recent successful applications for deeper optical imaging with Subaru and VLT.

X–ray data: The SXDS is the location of the deepest X–ray field covering a 1 sq deg region. This consists of a 100ks central XMM observation, surrounded by 6x50ks flanking fields. Most of the XMM observations have already been made in A0–1.

Optical data: Subaru imaging on Suprimecam has already been taken in GTO and open time. Recently as part of an Observatory Key Project an additional 13 nights of Suprimecam imaging were approved for B,R,I,z' to 5–sigma point source depths of of B=29, R=28, I=27, z'=26. Further information on the Subaru data can be found at http://www.naoj.org/staff/chris/SXDS/

To complement this data, the UKIDSS UDS team have recently secured additional deep imaging through the recent ESO call for ideas for long–term surveys. The plan is to use VIMOS on VLT to reach complementary depths of $U = 27$ and $V = 27$. The U–band is vital for identifying unobscured galaxies at $z \sim 3$ by the Lyman drop out technique (Steidel et al. 1996). Such objects will then be ideal targets for future follow–up spectroscopy with VLT. The V–band is also important, both for constraining possible B–band drop outs and for providing reliable UV continuum measurements of the SEDs of $z \simeq 3$ sources.

With a combination of U, V from VLT, B, R, I, z' from Subaru and J, H, K from WFCAM we will have a very powerful baseline for photometric redshift determination.

Far–infrared: This is a target field for the SIRTF SWIRE legacy project, although we intend to propose much deeper GO observations in open time.

Sub–mm data: An ambitious SCUBA survey has been proposed by the extragalactic UK Sub–mm community to cover a 0.5 sq degree region centred on this field to a depth of 8mJy at 850 microns (2mJy rms). The survey has just been approved. The major aim is to determine the clustering of sub–mm sources. In addition, the Balloon–Borne Large Aperture Sub–mm Telescope (BLAST) is due for launch in the winter of 2003 (http://www.hep.upenn.edu/blast/). This will cover the Subaru field at shorter sub–mm wavelengths and enable redshift estimates to be determined for the SCUBA sources.

Radio data: Deep radio observations are currently underway. The existing map indicates that there should be no problem (in terms of bright sources) in reaching substantially fainter limits (e.g. $5\sigma \simeq 50\mu$Jy).

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