THE UK INFRA-RED DEEP SKY SURVEY (UKIDSS)

A PROPOSED LARGE PUBLIC SURVEY WITH THE UKIRT-WIDE FIELD FACILITY

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1. INTRODUCTION

The science case for the UKIRT wide field facility falls into three overlapping areas. First, a wide range of problems can be attacked in traditional common-user open-time application mode (i.e. in PATT time). Second, there is a recognised need for Gemini precursor observations and support work. Finally however it gives us an opportunity to perform a large and ambitious public survey. Such a communal survey would (a) be an exciting and world-leading science project in its own right, (b) provide much of the Gemini precursor needs, and a launching point for more detailed UKIRT programmes, and (c) be a cost-effective way to run UKIRT.

This document does not constitute a bid for funding for the staff effort for such a public survey (although it does give an indication of the likely cost). Rather it is included in this GBFC paper as information in support of the UKIRT wide field facility proposal itself. The case for conducting a large public survey is, strictly speaking, separate from the case for the facility itself. One could build a wide-field facility and use it only in common-user application mode, and do much excellent science. But in our view a large public survey is so exciting in its own right that the opportunity to undertake such a survey is in fact a strong argument in favour of the facility.

2. THE NEED FOR SURVEYS AND ATLASES.

The basic argument for a public survey comes in two parts - (i) meeting the science aims of many different large sample projects in a communal way, and (ii) producing an atlas, whose eventual uses cannot be foreseen, but which will be a world resource.

2.1 Individual Surveys

Many astrophysical questions require large samples to address them, and others require rare objects to be found amongst large populations. Some such questions are best addressed by short well focussed experiments appropriate to small allocations in open time. Some problems require considerable amounts of telescope time, which however can still be achieved in open time by the formation of consortia with common aims which can hope to win larger allocations (for example the 2dF redshift survey). However, where the time required becomes a significant fraction of a year on one telescope, and/or where many different scientific projects potentially require overlapping or identical pieces of sky, it makes sense to produce the dataset required in a truly communal way, by a dedicated team.

2.2 Sky Atlases

Much of modern astronomy has sprung from the major sky atlases - the 3C catalogue, the Uhuru and Ariel V catalogues, the IRAS catalogue, the COBE sky-maps. Through much of this time the UK Schmidt photographic sky atlas (and its Palomar counterpart) has been the backbone of UK astronomy. As well as providing a fundamental reference and support of the space astronomy programme through identifications, it has been a source of science in its own right (eg Abell/ACO clusters, Lynds dark clouds, the APM galaxy catalogue). A large fraction of the science emerging from such sky atlases would have been impossible to predict beforehand. We can expect such productivity from an atlas whenever we make a quantum leap in wavelength, sensitivity, or field of view. The first high-resolution IR sky surveys (DENIS and 2MASS) are just now taking place but these are really equivalent to say the UGC or ESO catalogues rather than the Palomar/UK Schmidt surveys. The analogy is quite accurate as we are considering going more than 6 magnitudes deeper than DENIS.

The UK has the opportunity to undertake a marvellous project for relatively modest cost. Mark Casali has shown in previous GBFC presentations that the UKIRT wide field facility has a survey speed which is faster than any other existing or planned facility at K band, and matched only by the planned VLT IRMOS at J and H. However only a tiny fraction of the VLT could be made available for IR imaging surveys. (Much IRMOS time will be for spectroscopy). Likewise strong science could be done with an IR imager on the INT, but it would take many times longer to construct a truly world-beating atlas. It is only with the UKIRT wide field that there is a realistic prospect of producing the next generation IR sky atlas.

3. KEY SCIENCE DRIVERS FOR SURVEY DESIGN

It may be possible eventually to conduct a complete Northern sky survey (and in conjunction with a new southern telescope, perhaps an all-sky survey) but for now it is more realistic to consider a partial survey. We do not present a full science case here, but rather consider selected points that seem likely to drive the optimum design for the survey.

3.1 Generic Atlas Drivers

Any IR atlas must include the Galactic Plane. The longitude limits are set by the UKIRT declination limits of +60 and -47, just including the Galactic Centre. The best latitude limit is not so obvious, but probably +/- 5 is good enough, except that some key nearby open clusters and star formation regions are at mid-latitude, b~15. Several of these are relatively close on the sky around RA = 3-6, suggesting a special mid-latitude survey. The sensible depth of a Galactic Plane survey is probably limited by stellar confusion, which needs further study in the K-band. We take K=20 as a good working compromise between confusion and depth - the confusion will certainly be severe very near the Galactic Centre, but it will probably be acceptable over most of the Plane.

At high latitudes the obvious thing to do is to match the Sloan Digital Sky Survey. The prospect of a quarter of the sky with complete optical and IR colours, and optical spectra, is extremely exciting. The Sloan survey is actually made of several parts. The footprint is approximately b>30, but an additional 2x50 degree strip will be surveyed near the SGP. In the main region, there will be a five band imaging survey complete to R=23 (5 sigma) but it is also intended to get spectra for all galaxies to B=19 and all quasars to B=20. Given the depth that we can reach in the IR in reasonable time, a reasonable aim would be to survey all or most of the Sloan area to a depth which matches the spectroscopic survey, and also to survey a smaller subset which matches the photometric survey (or perhaps the southern deep strip). Note that the UKIRT declination limit excludes some of b>30, but the accessible area is still approximately 9000 square degrees. The depth which "matches" emerges from more specific considerations below.

3.2 The "Local" Universe : galaxies at z<0.5

An IR selected sample gives us the chance to tackle large scale structure problems properly for the first time - optical and FIR selected samples are strongly affected or even dominated by current star formation, whereas K-selection will trace stellar mass. We have an opportunity to achieve a K-selected redshift survey cheaply by simply selecting a K-limited subset of the Sloan spectroscopic survey, which should have median redshift around 0.1. The Sloan project have already made the case for needing of the order one million galaxies and a large fraction of the sky, so we need to at least roughly match the Sloan area and depth. Galaxy colours are in the range B-K ~2-5 depending on type so for a limit of B=19 we need K=17, but at good signal to noise, so a 5sigma depth of K=19 is needed to give to 30 sigma at K=17 . We will also of course be sensitive to rare extremely red objects - perhaps the most interesting objects will be those that we see and Sloan doesn't, and which will need following up with UKIRT open time spectroscopy. Many other fascinating galaxy projects would be accomplished with such a very large and moderately deep survey. For example one could construct a BVRJHK "main sequence" for galaxies, and see how it varied with density or cluster age. One could search for the "missing dwarfs" predicted by CDM cosmology but not found in optical surveys (they could well have a single very old population and no subsequent star formation).

3.3 Galaxies at z=1-2

Very deep IR surveys are an excellent way to find very high redshift (z>3) galaxies, and a few hundred objects could address questions such as the history of star formation rate. Such objects will be dense on the sky and very faint, and thus good projects for open time. However the brightest very high redshift objects will be rare and will emerge from a large survey. At moderate redshifts (z=0.5 to 2) we can anticipate locating many thousands of objects, and estimating photometric redshifts, in conjunction with the Sloan photometric survey, as the 4000 A break moves through the red optical and into the IR. This opens up the possibility of measuring the growth of structure, enabling direct tests of cosmology, especially Omega and Lamda, independent of star formation complications. Based on the small deep IR surveys carried out so far, a survey to K=19 would be mostly local but with a tail of objects out to z<1, and would need both optical and IR colours for photometric redshifts. A survey to K=21 would produce galaxies in the range z=0.5 to 2, and JHK colours alone could yield a crude photometric redshift. The Sloan photometric survey reaches R=23. At low redshifts, this corresponds to B~25 and K=20-23 depending on galaxy type. However at higher redshifts the K-dimming is much more drastic in the optical than in the IR. For z=1-2 galaxies, a K=20 survey would easily match the depth of Sloan main area, and K=21 would go beyond it. The best strategy is therefore probably to go to K=21 in the Sloan deep southern strip. The area required can be roughly estimated from the fact that at z=1 a 100 Mpc box is about 5 degrees across. To address the growth of clustering we would need perhaps 10 such contiguous fields. A survey size of around 250 square degrees is therefore needed to K=21; this would cover the Sloan SGP strip and extend northwards beyond it.

3.4 Quasars

Stars have convex SEDs whereas quasars have straight or even concave SEDs on log-log plots. A wide spread of colours across the optical-IR therefore gives the clearest possible separation of quasars from stars - see the VJK diagram from Steve Warren in the accompanying paper. At z>2 the use of the IR becomes particularly important as the optical wavebands are cut away by intergalactic absorption. Finally the K-band insensitivity to reddening would allow us to find the obscured quasar population which may explain the X-ray background and which may outnumber normal quasars by 3 to 1. The DENIS and 2MASS surveys will only get to the tip of the iceberg. To obtain a complete census of local quasars we need to match the intended quasar spectroscopic depth of the Sloan survey, B=20. For normal quasar colours this corresponds to K~17, but good S/N would be wanted so a 5 sigma depth of K=19 would be needed. (Similar to the local galaxy requirements.) Such a survey however is likely to produce large numbers of reddenened quasars not found in the Sloan survey. Spectroscopic follow up of sub-samples will satisfy many quasar addicts for years to come. A final point is that coverage in several passes in successive years would give variability information of unprecedented quality for the quasar population as a whole.

At moderately high redshifts, z=2-3, the completeness of UVX samples must be considered suspect, so that evolution studies with IR selected samples is a prime aim. However only a few thousand objects are needed, the surface densities should be high, and one wants deep images to reach down the luminosity function, so such programmes are probably best in open time. At high redshifts however (z>3) a large survey is needed. It is vital to know if any quasars exist beyond z=5. They may exist but could be extremely sparse on the sky both because of intrinsic rarity and because we can see only the most luminous objects. Current optical surveys find at most a few z>4 quasars per Schmidt field, although such surveys may be highly incomplete. At z=5 an object like 3C273 will be approximately K=21 if qo=0.5 and K=23 if qo=0; by z=7 it would have K=22 or K=24. The medium-sized deep survey required for z=1-2 galaxies, to K=21 over a few hundred square degrees, would therefore be of great interest to limit the z=3-5 behaviour of quasars, but a serious probe to z>5 would need a survey of perhaps a few square degrees to K=23.

3.5 Low mass stars and brown dwarfs

The subject of brown dwarfs is one which current IR work and surveys such as DENIS are just now turning from fantasy to reality, but the surface is only just being scratched. A prime aim must be to test BD numbers versus cluster age. A Galactic Plane survey would include dozens of open clusters with a variety of ages. However they are typically many times further away than the Pleiades, so that one needs to expose perhaps a hundred times deeper, to around K=20. A second prime aim must be to push from the hydrogen burning limit of (around 0.1 Msun or 100 Jupiter masses) to the putative fragmentation limit (around 10-20 Jupiter masses). There are five obvious very nearby clusters in which this can be achieved. Of these Coma is above the UKIRT declination limit, and the Ursa Major cloud is very near the limit. The other three (Pleaides, Hyades, Taurus-Auriga) are all a few degrees across and whats more are close in the sky, strongly suggesting they could be covered in a single mid-latitude survey. At the distance and age of the Hyades (45pc, 600 Myr) a 20 Jupiter mass BD is expected to have K=20, and a 10 Jupiter mass BD has K=22.3. (The Pleiades is further but younger, so that expected BD fluxes are grossly similar). These numbers strongly suggest that a multi-cluster large area survey to K=20, 20 Jupiter masses, could be carried out in public mode, and deeper selected areas left to open time programmes.

A third prime aim must be to find significant numbers of field brown dwarfs in the disc population. The fact that the best nearby clusters are all at b~15 is not a coincidence but reflects the scale height of the nearby young population. Likewise this suggests that a Galactic Plane survey will miss many of the nearest and brightest BDs. On the other hand a high latitude survey at b>30 will only find extremely nearby objects; there may be very few of these unless the mass function is much steeper than is currently expected. It is essential that a variety of latitudes is sampled. To find field BDs, JHK colours and especially K are essential - because of molecular absorption, such objects are expected to be blue in JHK, not red. However an additional discriminant would be proper motion, as all such objects will be very close. As with quasar variability, this suggests we should accumulate the depth required by several passes in successive years.

3.6 Star formation regions

Within obscured star forming regions, an aim would be to reach the main sequence limit in the K-band, which would then be deep enough to satisfy many other aims. As with the BD calculation, to do this for star forming regions to a distance of around 500 pc through the Galactic Plane survey then suggests K~20, similar to the depth suggested by the confusion limit at small longitudes. Outside the Plane, covering the greater Orion star forming region seems an obvious aim. This is only about 30 degrees from the Hyades, and strongly suggests a mid-latitude survey covering all of Pleiades, Hyades, and Orion.

3.6 Galactic Structure

Star counts and kinematics for low mass stellar populations will be a very valuable addition to the studies that will come out of the digitised optical sky surveys. The key requirements are that a good range of longitudes and latitudes are covered, and that the best possible proper motion information is available, suggesting (as with the field brown dwarf survey and quasar variability) constructing all surveys in several passes over consecutive years.

4. PRELIMINARY SURVEY DESIGN

Putting the above considerations together we arrive at a survey design made of several parts of varying sizes and depths. This loses a little simplicity, but meets the various scientific aims with minimum time. The depth has been derived in K-band terms, but nearly all scientific goals need JH and K. For simplicity we assume that J and H together take as much time as K for a "matching" depth although of course what depth matches depends on scientific aim. We assume a design for the UKIRT wide field as presented to the last GBFC and the Edmunds ad hoc panel, with a 30 arcminute field, 0.4" FWHM images achieved throughout by tip-tilt, and sensitivity such that K=20.1 can be achieved over one square degree in one hour. (The current design assumes 4 contiguous fields achieved via the pyramidal mirror.) Hours are converted to nights assuming an average of 10 hours/night. Times calculated do not make any weather allowance. The calendar years required will be larger than the used survey time depending on what fraction of UKIRT time is used for the public survey, and what fraction for open user time. For now, we assume 50%.

All the major surveys would be done in several co-added passes in consecutive years, to give variability and proper motion information, as well source reliability confirmation.

4.1 High Latitude Sky Atlas

We aim to match the Sloan spectroscopic survey at b>30, Dec<58, giving approx 9000 square degrees, to K=19. This takes 1100 hours. Doubling the time to do JH as well, and doubling again on the assumption of 50% survey time, the high latitude sky atlas could be completed in 1.2 years.

4.2 Galactic Plane Atlas

Here we cover two separated strips, l=350 to 90 and l=150 to 250, each covering /b/<5, giving a total area of 2000 sq. degrees. The required depth is K=20, taking 1660 hours. Including JH and assuming a 50% rate this survey could be done in 1.8 years. It is similar in duration to the high latitude atlas and covers a complementary RA range, so they fit very well together.

4.3 Mid Latitude Survey

To include Pleaides, Taurus-Auriga, Hyades, and the greater Orion region, as well as covering the general nearby disc population, we propose surveying a region at l=160 to 215 and b=-12 to -30. This is 920 square degrees. To a depth K=20 this would take 765 hours. Assuming JH coverage and a 50% rate this uses 0.8 years total. (If time allowed, extending to b=-5 to join the Galactic Plane survey would obviously be appealing).

4.4 Deep Survey

To study moderate redshift galaxies and the growth of structure (and doubtless many other exciting projects we can't imagine yet) we propose surveying 250 sq. degrees of high latitude sky to a depth K=21. This would take 1200 hours. Allowing for JH and a 50% rate this survey would use 1.3 years.

4.5 Very Deep Survey

To search for very high redshift quasars, and other rare objects, and more generally to probe unexplored space, we propose a very deep survey to K=23 covering 1 sq. degree (four fields). In practice such a very deep survey could be gradually accumulated as a filler during the other surveys, revisiting the selected field repeatedly. This would take 210 hours for K-band exposure only. Allowing for JH and 50% rate, it would use 0.2 years.

5. SURVEY SCHEDULE

The total survey time, assuming all three bands, and 50% of UKIRT time being available for survey mode, is 5.3 years. Allowing for weather, the complete programme could be completed in perhaps seven years. If funding for the UKIRT wide field facility could start in 99/00, it could potentially be delivered in 01/02 and serious survey observations could perhaps start by early 2003. The full programme would then be complete around 2010. (Survey management and software effort would need to start in 2001). Note that Sloan observations are just about to start (first light images have recently appeared on the Web) and should be finished by about 2004. There is a two year gap before Sloan data becomes public, but this applies in slice-by-slice releases rather than waiting for the whole survey. Likewise if we release the IR survey data in slices to match the Sloan areas, the data can immediately be used with Sloan colours and redshifts for scientific purposes.

If a "fast track" wide field IR imager is built for the INT first, limited staff effort at the ATC and elsewhere means that a subsequent UKIRT programme, if still funded, would be delayed by perhaps two years. The impact on the IR survey programme (as opposed to the UKIRT facility) is less clear, depending of course on whether we undertake a "precursor" JH survey on the INT.

6. OWNERSHIP, OPERATION, AND MANAGEMENT OF SURVEY

Our proposal is that, by analogy with the Schmidt Surveys, the survey would be a project of the Joint Astronomy Centre, but carried out in collaboration with the Edinburgh Wide Field Astronomy Unit (WFAU), on behalf of the UK community. The survey would be public with no proprietary period, and released in stages as completed, as is being done by NRAO with the NVSS survey. Survey strategy would be designed by JAC and Edinburgh jointly, following agreed science goals set by peer review. Final responsibility and right of decision in contentious areas would rest with the JAC and/or the UKIRT board. The division of responsibilities has not yet been fully discussed. However a likely division is that Edinburgh would be responsible for overall project management, data reduction including calibration and quality checks, catalogue construction and user interface, and data archiving and distribution. The JAC would be reponsible for survey operations and immediate quality control, and perhaps construction of pipeline software and tiling algorithm.

Although the main push for the UKIRT wide field facility itself has come from the ATC, and for the survey from Edinburgh University, many other astronomers from across the UK have been closely involved in setting science goals and influencing the design. It seems vital to keep such key scientists closely involved. It is possible that a consortium may form to set top-level science goals, and the JAC could choose to form its own Science Advisory Group from such key community members, as the AAO is proposing to do for the 6dF redshift survey. Alternatively, PPARC could form a steering committee to provide advice on these issues; or finally the UKIRT board could act as such a steering committee. The key point is that one way or another a close community oversight and involvement should be maintained.

The working assumption is that observations would be carried out by UKIRT staff astronomers. (The cost implications are briefly considered below). An alternative that is being considered is that staff and postdocs from the UK could do the observing in large blocks. These could be drawn from staff at the Edinburgh WFAU or from other staff at interested institutions across the UK, as long as they clearly understood that they were working in public service mode. A final possibility is that survey operations will become sufficiently routine that TOs will be able to undertake the work, or even that it can be programmed and left to run on a night-by-night basis.

7. IMPACT ON OTHER UKIRT PROGRAMMES

We won't really know what the rational programme of use for our existing telescopes should be in the future until we see how Gemini works in practice. However UKIRT almost certainly has a continuing role as a high profile general purpose telescope, so 100% conversion to survey work is not appropriate. This is also made clear by the responses to the UKIRT board questionnaire, which showed enthusiasm for survey-mode work, but only up to around 50% of the time. We accept this, but our personal feeling is that survey time should reach this maximum, as we have the chance of doing something world class that otherwise simply would not happen. We actually suspect that other UKIRT programmes will benefit, and predict that a large fraction of UKIRT time will be taken up with individual spectroscopic programmes based at least in part on the IR survey data.

8. COST IMPLICATIONS.

We assume that the UKIRT Wide Field Facility has been funded and constructed. Additional cost implications should be considered for both operations and survey management and data reduction.

8.1 Operations costs

These have not yet been properly costed but it seems likely that they will be at worst cost neutral. There will be less call for "firefighting" technical support, both because open time will be reduced by a factor of two, and because maintenance work can be carried out in a flexible way during survey blocks of time. The PATT travel budget and administrative support attached to frequent visitors would be greatly reduced. (All those visiting University astronomers can be doing science instead of sitting on airplanes as well !) On the other hand, more staff astronomer effort could be required to carry out survey observations. Actually, staff astronomers are not necessarily needed for this purpose. TOs could easily be capable of carrying out survey observations. Of course MK rules dictate that two people are always present, but perhaps these survey observations could be done remotely from JCMT or Gemini, requiring the TO to visit UKIRT only when problems occur. Indeed, it should be possible to simply visit UKIRT at the beginning of the night, start a sequence of positions, and leave. Finally, an alternative that could be both cost-effective and involve the community would be to carry out observations with a small army of visiting postdocs from interested institutions across the UK. To minimise the travel budget, the postdocs would perhaps visit in small groups for several months, and actually observe in alternating weeks. None of these possibilities have yet been properly costed, but one can see from the above analysis that it is at least not the case that operations would cost more.

8.2 Survey management and data reduction

Significant SHEFC funded input can be expected from IfA staff. We also anticipate real scientific involvement from astronomers at several other UK institutions. Above this we estimate that perhaps four FTEs (probably actually four dedicated staff) would be required at IfA and/or JAC - a project manager, a programmer designing pipeline and cataloguing software and user tools; and two scientists working on data reduction and survey strategy, with assumed 30% personal research fractions. We envisage a preparatory phase starting a year before operations, and a post-operations phase lasting two years after. The project manager would work throughout - ten years. The programmer would work from preparations to two years into survey - four years. The PDRA scientists would work from operations start through to the end of the project - nine years. In total then we estimate that roughly 32 grant-funded staff years are required. This effort would be located at both Edinburgh WFAU and JAC. If this project becomes merged with other possibilities such as an INT survey or a new southern wide-field facility, it would probably be appropriate to plan staff effort jointly with the Cambridge CASU.

Given the timing and the expected profile of other WFAU projects, this staffing level will probably be consistent with overall roughly flat funding of the Edinburgh WFAU grant. The transfer to IfA is still under negotiation but nearly complete. The initial grant will be for five years with a first review in autumn 2001. That review point would contain the first formal bid for staff effort connected with an IR survey, although such plans have already been described to PPARC in peer reviewed documents concerning the WFAU transfer. For comparison, the anticipated SuperCOSMOS programme will have three scientists and 1.5 operators, and 6dF support will have the equivalent of one full-time scientist. The SuperCOSMOS programme remains high priority for at least five years but then would be under review. If the UKIRT survey was funded, we would probably continue SuperCOSMOS work after the first five years but with minimum staffing.

9. IMPACT ON OTHER UK TELESCOPES

Part of the point of the survey is to have a positive impact on Gemini programmes, but the IR survey will undoubtedly also provide a launching point for WHT, JCMT, and UKIRT open time programmes as well. The relation with the INT is more problematic, as was recognised by the formation of the

Edmunds ad-hoc panel. The INT already has a wide field focal station, and a world class optical wide field imager, and it is well recognised that it must devote its time even more to survey programmes than it does at the present. It may be that the best thing is to allow the INT to capitalise on this optical work, and concentrate IR work on UKIRT (if we have the funds to keep both telescopes open, which looks more likely now than a few months ago). However a wide field IR imager could be provided faster (and cheaper) for INT than for UKIRT, so it is very tempting to do this first, and to delay the UKIRT programme. In this case, the INT camera could be used solely in open time, and the grand survey saved for UKIRT. However, it is also tempting to plan a two phase survey, with J and H at INT, and K to follow. If this seems like the most fruitful way forward, we would expect to develop the overall survey programme in collaboration with both the ING and the Cambridge Survey Astronomy Unit, who currently take responsibility for the INT Wide Field Camera, and who are the originators of proposals for an INT fast-track IR wide field camera.

We can see how such an INT survey could fit in as follows. The High Latitude Atlas and the Galactic Plane Atlas are estimated to take three years for JHK on UKIRT. Using the relative survey speed figures from the Casali paper to the GBFC in January 1998 (which take accountnof aperture, seeing, and background) , and assuming that 50% of the INT is used for the survey, the JH components could be done in approximately five years on the INT. Such an INT survey could be started while the UKIRT wide field is being built, and finished while UKIRT is undertaking the K component and the deeper surveys. Apart from worries about whether such a survey speed is cost-effective, the other drawbacks to an INT pre-cursor survey are that the JH observations would be taken at a different time to the K observations, and with a different resolution, which would be particularly serious in the Galactic Plane survey.

More ambitiously, another proposal is being developed by J.Emerson (QMW, but acting as chairman of the Wide Field Astronomy Panel) in conjunction with NOAO to build a new southern 2.5m wide field IR optimised telescope. If this comes about, then it would be certainly be available for open time, but could also together with UKIRT in the long term be used to construct a complete all-sky IR survey to around K=19 or 20, which would then be the true counterpart of the Schmidt sky surveys.