# The UKIRT Infrared Deep Sky Survey becomes an ESO public survey

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## 1. Overview

UKIDSS is the next generation near-infrared JHK sky survey, the successor to 2MASS. UKIDSS will use the UKIRT wide field camera WFCAM, currently under construction in Edinburgh and scheduled for commissioning at the end of 2003. The camera uses four Rockwell Hawaii II 2048×2048 HgCdTe arrays (Figs 1 and 5). When commissioned WFCAM will have the widest field of view of any near-infrared camera in the world, capturing a solid angle of 0.21 square degrees in a single exposure. In addition to the wide field, the survey will provide a wealth of information revealed in the near-infrared because of the lower extinction.

UKIDSS is a UK initiative and was the idea of Andy Lawrence (IfA, Edinburgh) who is the UKIDSS Principal Investigator. As part of the in-kind contribution of the UK to the ESO membership joining fee the UKIDSS data (raw, processed, and image catalogues) will be available to the entire ESO community immediately the data enter the archive. UKIDSS is therefore an ESO public survey, and the purpose of this article is to inform the ESO community about UKIDSS, describing the plans, and highlighting the opportunities for VLT science. For more details visit the website www.ukidss.org (Fig. 1). The UKIDSS Consortium is a collection of some 60 UK astronomers who are responsible for the design and execution of the survey. We welcome the input of ESO astronomers to this effort (contact details are provided at the end of this article).

UKIDSS in fact consists of five surveys exploring both high and low Galactic latitudes to a variety of depths. The surveys will take some seven years to complete, finishing in 2010, and will require a total of 1000 nights on UKIRT. Details of the five surveys are summarised in Table 1. The Large Area Survey (LAS) covers 4000 square degrees at high Galactic latitudes, to K=18.4. This depth is three magnitudes deeper than 2MASS. The LAS will be the true near-infrared counterpart to the Sloan survey. The Galactic Plane Survey (GPS) will provide a panoramic clear atlas of the Milky Way disk, reaching K=19.0, surveying the strip to 5 degrees above and below the plane along a length 180 degrees. The Galactic Clusters Survey (GCS) will undertake a fundamental study of the faint end of the stellar initial mass function, imaging the nearest stellar clusters to a depth K=18.7. Finally two deep surveys, the Deep Extragalactic Survey (DXS) reaching K=21 over 35 square degrees, and the Ultra Deep Survey (UDS) reaching K=23 over 0.77 square degrees, will study galaxies at high redshifts. Fig. 2 plots the combinations of depth and area of the five elements of

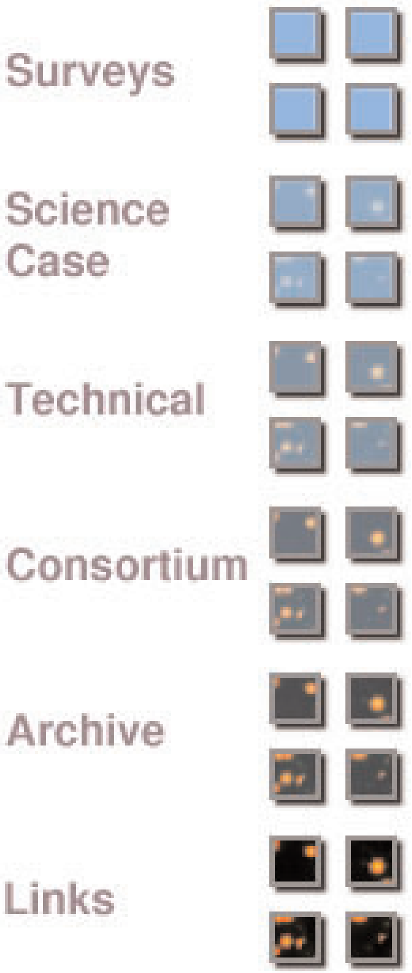


*Figure 1: This figure shows the UKIDSS website navigation menu (www.ukidss.org), and pictures WFCAM as night falls.*

*Table 1: Details of the five elements of UKIDSS. The quoted depths are total magnitude 5 sigma for a point source. The estimated number of nights for each survey includes an allowance for poor weather. The Y band covers the wavelength range 0.97–1.07 µm.*

| | Filter | Area<br>sq. degs | Mag. Limit<br>(Vega) | Nights |
|---|---|---|---|---|
| Large Area Survey<br>LAS | Y<br>J<br>H<br>K | 4000 | 20.5<br>20.0<br>18.8<br>18.4 | 262 |
| Galactic Plane Survey<br>GPS | J<br>H<br>K<br>$H_2$ | 1800<br><br><br>300 | 20.0<br>19.1<br>19.0<br>— | 186 |
| Galactic Clusters Survey<br>GCS | J<br>H<br>K | 1600 | 19.7<br>18.8<br>18.7 | 84 |
| Deep Extragalactic Survey<br>DXS | J<br>H<br>K | 35<br>5<br>35 | 22.5<br>22.0<br>21.0 | 118 |
| Ultra Deep Survey<br>UDS | J<br>H<br>K | 0.77 | 25.0<br>24.0<br>23.0 | 296 |

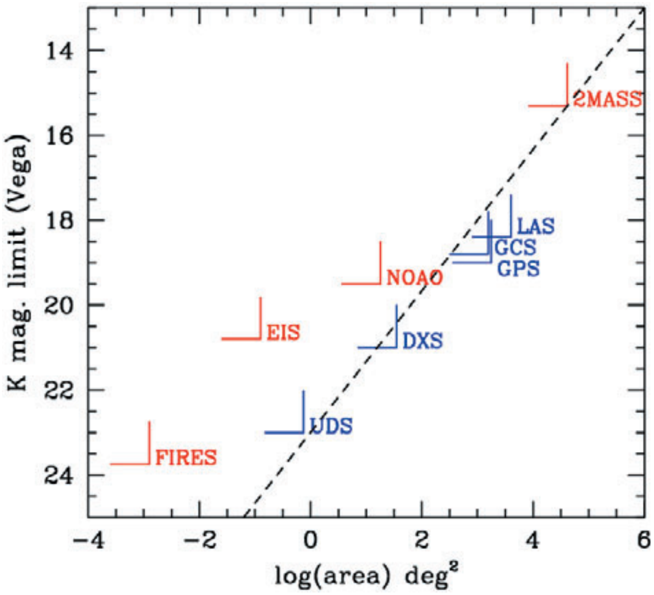


*Figure 2: Comparison of survey area and depth in K of UKIDSS against existing or planned near-ir surveys. Note the enormous range of the X axis, 10 orders of magnitude. The five UKIDSS elements are plotted in blue. The surveys for comparison, plotted in red, are: 2MASS, the NOAO deep survey, the ESO Imaging Survey EIS, and the very deep FIRES VLT image of HDF-S (see Fig. 3). The dashed line shows the Euclidian relation between number counts and depth, normalised to 2MASS. The position of a survey relative to this line is a measure of the volume of space surveyed. This illustrates, for example, that for surveys for brown dwarfs 2MASS will detect many more than the KPNO survey, and that the LAS is an order of magnitude bigger than 2MASS.*

UKIDSS, compared against some other near-ir surveys. The basic point illustrated in this plot is that at any depth UKIDSS will cover at least an order of magnitude more area than any existing or planned survey.

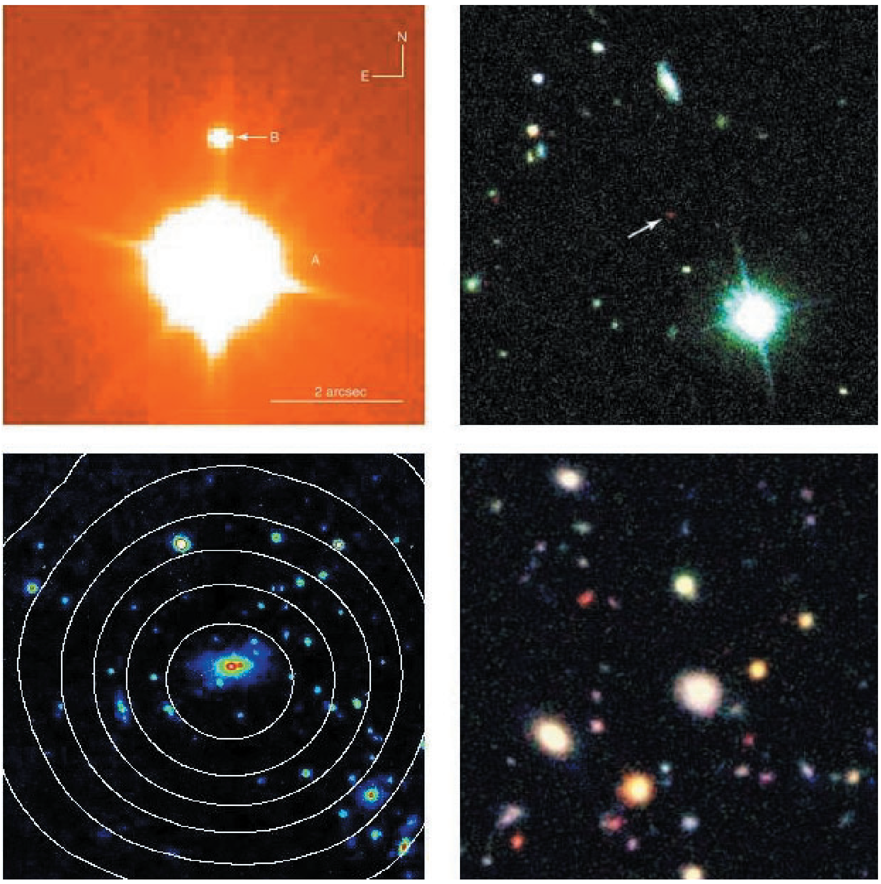


*Figure 3: Four of the principal generic targets of UKIDSS. Upper left: brown dwarfs - VLT/KUEYEN I-band image of the young brown dwarf TWA-5B, Neuhäuser et al., A&A, 360 (ESO PR 17a/00). Upper right: the highest-redshift quasars – optical colour composite of SDSS J1030+0524, z = 6.3, currently the most distant quasar known (courtesy Laura Pentericci; see article on p. 24 of this issue). Lower left: distant galaxy clusters – K-band image of the cluster J1226.9 + 3322, z=0.89, with X-ray contours overplotted (courtesy Laurence Jones and Simon Ellis). Lower right: galaxies at very high redshifts – near-ir JHK colour composite of a small 36×36 arcsec subsection of the deepest near-ir ground-based image yet taken, the FIRES observations of the HDF-S, Labbe et al. 2002, submitted (courtesy Marijn Franx).*

WFCAM will start UKIDSS early in 2004, just at the same time when VST/OmegaCam will enter operation on Paranal, thus offering the opportunity to combine optical and near-infrared data as appropriate for the various surveys.

## 2. Science headlines

Fig. 3 illustrates four of the principal generic targets of UKIDSS. The headline scientific goals are the following:

– to find the nearest and faintest sub-stellar objects
– to break the $z = 7$ quasar barrier
– to determine the epoch of re-ionisation
– to determine the substellar mass function
– to discover Population II brown dwarfs
– to measure the abundance of galaxy clusters at $1 < z < 1.5$
– to measure the growth of structure and bias from $z = 3$ to the present day
– to determine the epoch of spheroid formation
– to clarify the relationship between EROs, ULIRGs, AGN and protogalaxies
– to map the Milky Way through the dust, to several kpc
– to increase the number of known Young Stellar Objects by an order of magnitude, including rare types such as FU Orionis stars

## 3. The five surveys: LAS, GPS, GCS, DXS, UDS

Fig. 4 is a map showing the provisional locations of the different fields that will be covered by the five surveys. Since the announcement that the UK will join ESO the field selection has been adjusted to a more southerly configuration, to improve access from the VLT. The selection of fields for the first two years of observations is almost complete, and the choices will be posted on the UKIDSS web page in July this year. A brief description of each survey follows.

### *Large Area Survey (LAS)*

The LAS was conceived as the infrared counterpart to the Sloan Digital Sky Survey (SDSS), as well as an atlas for identification of sources detected in surveys at other wavelengths. SDSS fields covering 4000 square degrees will be observed in the four passbands YJHK, with a second pass in J a few years later, for proper motions. Opening the near-ir window will greatly clarify the make-up of low-redshift galaxies in terms of mix of stellar populations and dust content. The long-wavelength data will also enhance the detectability of distant galaxy clusters, as well as reddened X-ray/far-IR/radio survey sources. However it is the opportunity for finding new classes of rare objects, because of the great volume surveyed (Fig. 2), which is the most exciting prospect of the LAS. In the search for brown dwarfs the LAS will explore an order of magnitude more volume than 2MASS, and therefore will be the most powerful survey for both the coolest and the least luminous dwarfs. We hope to uncover the cool sequence extending beyond type T, also to detect Population II brown dwarfs using proper motion, and to discover the lowest mass dwarfs, possibly free-floating planets at sub-parsec distances.

We anticipate similar success in the search for the highest redshift quasars. Building on the success of the SDSS in finding $z > 6$ quasars (see the article by Pentericci et al. on p. 24 of this issue) we hope to extend this frontier to redshift $z = 7$ and beyond. This work employs the Y band, which covers the wavelength range 0.97–1.07 μm. This filter is distinct in wavelength from the SDSS z′ band, and the z′-Y colour is crucial for the highest redshift quasars, so we preferred to give the filter a new name rather than call it z(infrared).

In summary, the LAS aims to discover both the nearest (outside the solar system) and the farthest known objects in the Universe! In between these two extremes the LAS will also pick up the intrinsically brightest Extremely Red Objects (ERO galaxies) over a volume thousands of times bigger than so far explored.

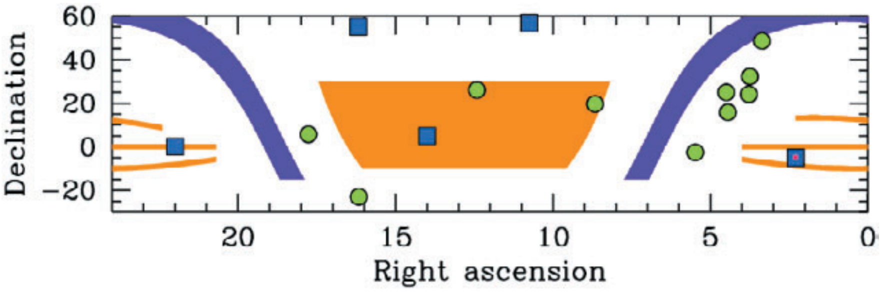


*Figure 4: This plot marks the provisional locations of the survey fields, which are currently being finalised. The LAS is shown in orange, and will cover the most southerly of the northern Galactic hemisphere SDSS stripes, as well as the three southern Galactic hemisphere SDSS Stripes. The GPS is shown in purple. The gaps in Galactic longitude coverage of the GPS are imposed by declination constraints 60° > δ > –15°. The GCS fields are marked by green circles. The DXS will choose four fields from the 5 fields marked by blue squares. The UDS field selected is the Subaru-XMM field, located at J0218-05, and is marked by a small red square inside the DXS field at that location.*

## *Galactic Plane Survey (GPS)*

The GPS will map in JHK half the Milky Way within latitude ± 5 degrees, covering arcs of longitude $15° < \ell < 107°$, and $142° < \ell < 230°$ (Fig. 4). Currently under discussion is the possibility of extending the survey by including fields in the Galactic bulge, as well as a thin strip extending into the Galactic centre. The GPS will be scanned three times in K, improving the depth to K = 19.0 and providing variability information. This is deep enough to see all the way down the IMF in distant star formation regions, to detect luminous objects such as OB stars and post-AGB stars across the whole Galaxy, and to detect G-M stars to several kpc. Additionally a narrow-band molecular hydrogen survey over a smaller area (300 square degrees) will be conducted in the Taurus-Auriga-Perseus dark cloud region.

The principal science drivers of the GPS are: (1) creation of a legacy database and 3-D Atlas; (2) study of star formation and the IMF with emphasis on environmental dependence; (3) detection of counterparts to X-ray and gamma-ray sources; (4) AGB stars, PPN and Planetary Nebulae, including detection of brief phases of stellar evolution; and (5) brown dwarfs: the GPS is similar in scope to the LAS in this regard.

## *Galactic Clusters Survey (GCS)*

The GCS is aimed at the crucial question of the sub-stellar mass function. The stellar mass function is well determined down to the brown-dwarf boundary but more or less unknown below, and the question of whether the IMF as a whole is universal is unanswered. The GCS will survey eleven large open star clusters and star formation associations in JHK, with a second pass in K for proper motions. These clusters are all relatively nearby and are several degrees across. The GCS improves on current studies, not primarily by going deeper, but by collecting much larger numbers, and examining clusters with a range of ages and metallicities in order to address the issue of universality. The mass limit reached varies somewhat from cluster to cluster, but is typically near 30 Jupiter masses.

## *Deep Extragalactic Survey (DXS)*

The DXS will map 35 square degrees of sky to depths of K = 21, and J = 22.5, in three separate regions. The theme of the DXS is a comparison of the properties of the Universe at $1 < z < 2$ against the properties of the Universe today. The DXS will survey a similar volume at these redshifts to the 2dF and SDSS volumes, and the near-infrared gives coverage of the same rest-frame wavelengths as SDSS. Much of the DXS science relies on multi-wavelength coverage. As the final fields are selected over the next year, at the same time as *XMM-Newton*, GALEX, CFHLS, VIRMOS, VST, and SIRTF plans are finalised, international multi-wavelength key areas will emerge.

The principal goal of the DXS, which sets the scope of the survey, is the measurement of the abundance of rich galaxy clusters at $z > 1$. The purpose is to obtain constraints on cosmological parameters. Ultimately we hope to make an important contribution to reaching beyond the three-parameter $H_0$, $\Omega_m$, $\Lambda$ cosmology that describes the geometry and dynamics of the Universe, to obtain useful constraints on the dark energy equation of state parameter $w = P/\rho$, and thereby to gain insight into the nature of the dark energy: cosmological constant or quintessence. Two other important goals of the DXS are (i) to provide the photometric catalogues for surveys at $z > 1$, including a redshift survey similar in scope to the 2dF galaxy redshift survey, to measure the evolution of large scale structure, and (ii) to quantify the contribution from both star formation and AGN to the cosmic energy budget, as a function of wavelength over the X-ray to far-infrared region, and to measure clustering for the different classes of object; normal galaxies (by type), starbursts, EROs, AGN.

## *Ultra Deep Survey (UDS)*

The UDS aims to produce the first large-volume map of the Universe at high redshift, surveying a region 100 Mpc comoving across and 2 Gpc deep ($2 < z < 4$). Essentially the aim is to go as deep as is feasible over an area of one WFCAM tile (four pointings, Fig. 5). The depth has been chosen by reference to the detectability of a $z = 3$ $L_*$ elliptical that formed at $z = 5$. Accounting for the surface-brightness profile of such a galaxy, the required equivalent point-source depth is K = 23.

The prime aim of the UDS is the measurement of the abundance of high-redshift elliptical galaxies. Supplementary goals are the measurement of the clustering of galaxies at $z = 3$, and clarification of the relationship between EROs, ULIRGs, AGN and protogalaxies. The abundance of ellipticals at high redshift is a key test of hierarchical the-

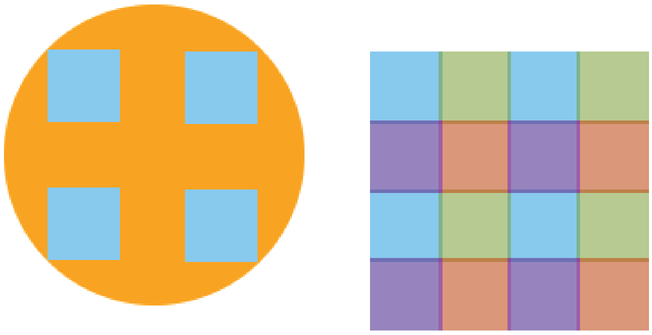

*Figure 5: Left: Focal plane arrangement of WFCAM. Each array (blue) is 2048 × 2048 pixels, with pixel size 0.4 arcsec. The 2 × 2 arrangement of arrays is contained within a circular field of diameter 0.97°. Right: Filled-in tile after 2 × 2 macro-steps. Allowing for the overlaps, the solid angle of a tile is 0.77 square degree. The deepest survey, the UDS, will cover a single tile.*

ories of structure formation, and the scope of the UDS is sufficient to distinguish between current competing models. The inspiration for the UDS came from the success of the HDF as a public legacy database. In the same way we expect that the UDS will be used for many important science projects that have not yet been thought of.

## 4. WFCAM: The UKIRT Wide-Field Camera

WFCAM is a cryogenic Schmidt-type near-ir camera under construction at the UK ATC in Edinburgh. The focal plane will hold four 2048 × 2048 PACE HgCdTe arrays. The spacing between detectors is 90% of the array width. The array configuration is illustrated in Fig. 5 (left). The pixel size is 0.4 arcsec, so the instantaneous exposed field of view of WFCAM is 0.21 square degree. With this configuration a single complete seamless 4 × 4 tile is achieved in four pointings, as illustrated in Fig. 5 (right). Accounting for overlaps the solid angle of a single tile is 0.77 square degree.

The WFCAM focal plane has a diameter 1.0°. The wide field of view has been achieved by a novel forward-Cassegrain design which achieves a high degree of off-axis correction and includes a cold pupil stop. Further information can be found at www.roe.ac.uk/atc/projects. Tip-tilt image stabilisation will be achieved using the existing tip-tilt hexapod stage with a new *f*/9 secondary mirror. The large pixel size was chosen to maximise survey speed. With the good image quality enjoyed by UKIRT the median seeing psf will be undersampled. We propose to microstep with a 2×2 *N*+0.5 pixel step to improve the sampling, interlacing the data to create the final image.

## 5. Consortium membership

Membership of the consortium implies a commitment from the individual to participate fully in the work of the consortium, which includes undertaking technical studies, preparing proposals and reports to the UKIRT Board, and contributing to the observing effort at the level of up to 7 nights per year, or equivalent contribution of effort in some other form. Interested astronomers should contact either Steve Warren (sjw4@ic.ac.uk), or Andy Lawrence (al@roe.ac.uk).

*The Horsehead Nebula – ESO/MPG 2.2-m telescope. (ESO PR Photo 02a/02.)*