Scientific goals of the UKIRT Infrared Deep Sky Survey

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ABSTRACT

UKIDSS is the next generation near–infrared sky survey. The survey will commence in early 2004, and over 7 years will collect 100 times as many photons as 2MASS. UKIDSS will use the UKIRT Wide Field Camera to survey 7500 square degrees of the northern sky, extending over both high and low Galactic latitudes, in JHK to K=18.5 (over three magnitudes deeper than 2MASS). UKIDSS will be the true near–infrared counterpart to the Sloan survey, and will produce as well a panoramic clear atlas of the Galactic plane. In fact UKIDSS is made up of five surveys and includes two deep extra–Galactic elements, one covering 35 square degrees to K=21, and the other reaching K=23 over 0.77 square degrees. This paper provides the details of the five UKIDSS surveys and describes the main science goals.

Keywords:

1. INTRODUCTION

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. When commissioned WFCAM will have the widest field of view of any near–IR camera in the world, capturing a solid angle of 0.21 square degrees in a single exposure.

UKIDSS was the idea of Andy Lawrence (IfA, Edinburgh) who is the UKIDSS Principal Investigator. UKIDSS in fact consists of five surveys covering a range of depths and areas at both high and low Galactic latitude. The UKIDSS Consortium is a collection of some 80 astronomers who are responsible for the design and execution of the surveys. For more details visit the website http://www.ukidss.org. The data become public to the whole ESO astronomy community as well as part of the Japanese astronomy community immediately they are entered into the archive. There will be a proprietary period, probably 18 months, before allowing world access.

All magnitudes quoted in this article are on the Vega system.

2. 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. 1 LHS. The pixel size is 0.4 arcsec, so the instantaneous exposed field of view of WFCAM is 0.21 square degrees. With this configuration a single complete seamless 4 × 4 tile is achieved in four pointings, as illustrated in Fig. 1 RHS. Accounting for overlaps the solid angle of a single tile is 0.77 square degrees.

The WFCAM focal plane has diameter one degree. 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.

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Figure 1. Left: Focal plane arrangement of WFCAM. Each array is 2048 $\times$ 2048 pixels, with pixel size 0.4 arcsec. The $2 \times 2$ arrangement of arrays is contained within a circular field of diameter 0.97 degrees. Right: Filled–in tile after $2 \times 2$ macro–steps. Allowing for the overlaps, the solid angle of a tile is 0.77 square degrees. The deepest survey, the UDS, will cover a single tile.

Further information can be found at http://www.roe.ac.uk/atr/projects. Tip–tilt image stabilisation will be realised 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 plan to microstep with a $2 \times 2$, $N + 0.5$ pixel step to improve the sampling, interlacing the data to create the final image.

3. FIVE SURVEYS

UKIDSS 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 $K=18.4$ ($5\sigma$). 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.
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 $0.97 - 1.07\mu m$.

| Survey                  | Filter | Area (sq. degs) | Mag. limit (Vega) | Nights |
|-------------------------|--------|-----------------|-------------------|--------|
| Large Area Survey       | Y      | 4000            | 20.5              |        |
| LAS                     | J      |                 | 20.0              |        |
|                         | H      |                 | 18.8              |        |
|                         | K      |                 | 18.4              |        |
| Galactic Plane Survey   | J      | 1800            | 20.0              |        |
| GPS                     | H      |                 | 19.1              |        |
|                         | K      |                 | 19.0              |        |
|                         | H$_2$  | 300             | ...               |        |
| Galactic Clusters Survey| J      | 1600            | 19.7              |        |
| GCS                     | H      |                 | 18.8              |        |
|                         | K      |                 | 18.7              |        |
| Deep Extragalactic Survey| J     | 35              | 22.5              |        |
| DXS                     | H      | 5               | 22.0              |        |
|                         | K      | 35              | 21.0              |        |
| Ultra Deep Survey       | J      | 0.77            | 25.0              |        |
| UDS                     | H      |                 | 24.0              |        |
|                         | K      |                 | 23.0              |        |

Fig. 2 plots the combinations of depth and area of the five elements of UKIDSS, compared against some existing or planned near–ir surveys. The short-dashed line compares surveys against 2MASS in terms of number of photons collected. In this sense the KPNO deep survey and the deepest element of EIS will, when completed, be comparable to 2MASS. Relative to this line each of the UKIDSS elements is a factor about 30 larger in area. Taken as a whole UKIDSS is two orders of magnitude more ambitious than any survey currently completed or underway.

In the same figure the long-dashed line compares surveys against 2MASS in terms of the volume mapped. This calculation assumes the spatial distribution of objects is uniform and that space is Euclidian, so is appropriate, for example, for estimating the relative numbers of brown dwarfs. In this respect the summed volume of the three shallow UKIDSS surveys, the LAS, GPS, and GCS, is about 20 times the 2MASS volume.

Fig. 3 is a map showing the planned locations of the different fields that will be covered by the five elements. After the UK joined ESO the field selection was adjusted to a more southerly configuration, to improve access from the VLT.

4. SCIENCE GOALS

4.1. Science headlines

The headline scientific goals of UKIDSS are the following:

- to find the nearest and faintest sub–stellar objects
- to break the $z = 7$ quasar barrier
Figure 2. Comparison of survey area and 5σ depth in K of existing and planned near–ir surveys. Note the enormous range of the X axis, 10 orders of magnitude. The most ambitious existing or planned surveys, besides UKIDSS, are plotted light. These are: 2MASS, the KPNO deep survey, the ESO Imaging Survey EIS, and the very deep FIRES VLT image of HDF–S. The five UKIDSS elements are plotted dark. The short-dashed line, normalised to 2MASS, plots the relation $\text{area} \propto 10^{-0.8K}$, which is the trade–off between area and depth for a fixed amount of telescope time (for sky–limited observations). The position of a survey relative to this line is a relative measure of the total number of photons collected. The long–dashed line, again normalised to 2MASS, plots the relation $\text{area} \propto 10^{-0.6K}$. The position of a survey relative to this line is a relative measure of the volume of space surveyed. [The different slopes of the two lines illustrate the point that for a fixed amount of telescope time a wide, shallow survey maps more volume than a deep, narrow survey.]
Figure 3. This plot marks the planned locations of the survey fields. Note that UKIRT lies at latitude $+20^\circ$. The ten GCS fields are marked by circles and the four DXS fields by squares. The UDS field is the Subaru/XMM–Newton Deep Survey field, which lies at the centre of the DXS field located at $J0218 - 05$. The GPS fields are the broad solid bands. The GPS covers the sections of the Galactic plane within $-5^\circ < b < +5^\circ$ and $-15^\circ < \text{Dec} < +60^\circ$, plus a narrower extension to the Galactic centre (marked GC). The LAS fields are the unfilled curved bands, and are SDSS stripes. Further details are provided on the web pages at http://www.ukidss.org.

- 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

The science goals of the five surveys are described individually below.

4.2. Large Area Survey (LAS)
The LAS was conceived as the infra–red 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 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 object, 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 (called Y dwarfs by Kirkpatrick), 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 we hope to extend this frontier to redshift $z = 7$ and beyond. This work employs the Y band, which covers the wavelength range $0.97 - 1.07 \mu m$. The bandpass of Y is illustrated in Fig. 4. 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 have preferred to give the filter a new name rather than call it $z$(infrared). Hillenbrand et al. describe a similar filter, and coincidentally have given it the same label.

In summary, we hope with the LAS to discover both the nearest (outside the solar system) and the farthest known objects in the Universe.

4.3. Galactic Plane Survey (GPS)

The GPS will map in JHK half the Milky Way within latitude $\pm 5^\circ$, covering arcs of longitude $15^\circ < l < 107^\circ$, and $142^\circ < l < 230^\circ$ (Fig. 3), plus a thinner strip extending into the Galactic centre and from there up into the bulge. 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.

4.4. 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 \(25M_{\text{Jupiter}}\).

4.5. Deep Extragalactic Survey (DXS)

The DXS will map 35 square degrees of sky to depths of K=21, and J=22.5, in four separate regions. The four fields are XMM–LSS, Lockman Hole, Elais–N1, and VIRMOS–4. The theme of the DXS is a comparison of the properties of the Universe at \(1.0 < z < 1.5\) against the properties of the Universe today. The DXS will survey a similar volume at these redshifts to the 2dF and Sloan Digital Sky Survey (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 and the choice of the four fields took account of existing or potential coverage by XMM–Newton, GALEX, CFHLS, VIRMOS, VST, and SIRTF.

The principal goal of the DXS, which sets the scope of the survey, is the measurement of the abundance of rich galaxy clusters at \(1 < z < 1.5\). The purpose is to obtain constraints on cosmological parameters. Ultimately we hope to make an important contribution to reaching beyond the three–parameter \(H_0, \Omega_m, \Omega_L\) 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 explore quintessence models. Two other important goals of the DXS are (i) to provide the photometric catalogue for a redshift survey at \(z > 1\), 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.

4.6. Ultra Deep Survey (UDS)

The UDS aims to produce the first large–volume map of the Universe at high redshift, \(z = 3\), 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. 1). 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. Secondary 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 theories of structure formation, and the scope of the UDS is sufficient to distinguish between
current competing models. The inspiration for the UDS came from observing 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.

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