UKIRT Review Panel Report
October 5th 2005

Executive Summary

The panel considers UKIRT to be a remarkably efficient and well-run observatory whose recent scientific output is commendable. An effective and appropriate transition to include a significant fraction of `campaign mode' science is underway following the successful commissioning of WFCAM and we make some suggestions for future reviews of the UKIDSS programs. Our panel is strongly of the opinion that UKIRT has a vital and promising scientific future as a 4 metre telescope on a strategically important Northern hemisphere site. We make specific recommendations to PPARC on how to proceed in evaluating various options as well as on improving synergies with larger telescopes on Mauna Kea.

1. Introduction

This report contains the recommendations of a panel appointed by the 3.8m UK Infrared Telescope (UKIRT) Board whose charge is to consider the current scientific utility of the telescope in the context of other developing infrared facilities worldwide and to evaluate the prospects for its continued exploitation over the next 10-15 years. Panel membership and the agreed charge are given in Appendices I and II respectively.

In undertaking this task, the panel chair attended a national community meeting held in Birmingham, UK where the future role of UKIRT was the underlying discussion theme. At that meeting, specific science directions and instrumentation proposals were presented and discussed. The panel received relevant input from the UKIRT Board, the Head of Operations and other individuals prior to visiting the JAC for two days in late June. A summary of the documentation received is given in Appendix III.

The UK has an admirable reputation for taking bold and imaginative steps in upgrading, and thereby giving a new lease of life to, its well-established telescopes. The 2dF facility on the AAT is perhaps the best-known example, the panoramic infrared imager WFCAM recently commissioned on UKIRT is destined to follow suit.

UKIRT is currently at a major transition point in its history. Prior to the commissioning of WFCAM, the facility served admirably as a general-purpose infrared facility for a wide variety of solar system, Galactic and extragalactic science. With the advent of general-purpose infrared instruments on larger telescopes to which the UK community has access (Gemini-N/S, VLT), it is logical that UKIRT has turned towards a `campaign' mode of operation whereby a significant fraction of time is being devoted to an ambitious survey – the UK Infrared Deep Sky Survey (UKIDSS).

A major question which motivated the panel's discussion is the long-term prospects for UKIRT, say in 2010 or later, when an ambitious set of second generation infrared instruments will be arriving on the current suite of 8 and 10-m telescopes. The launch of James Webb Space Telescope may be imminent and a future generation of 20-60 m ground-based telescopes may be under construction.

Recognizing the above, the panel decided to consider its charge in terms of three distinct eras:

- The pre-UKIDSS era, where the scientific productivity of UKIRT as a general facility can be gauged alongside that of other, comparable facilities; the goal here is to provide a critical evaluation of the current facility.

- The UKIDSS era, whose duration and scope will depend on progress and later reviews; a key issue here is the degree to which the survey can remain competitive as other survey cameras are commissioned as well as the degree to which some flexibility might be needed in the use of WFCAM to address new scientific developments.

- The post-UKIDSS era, roughly defined as one commencing when the presently conceived UKIDSS program is complete. The key questions to address are whether a 4m facility can play a valuable role alongside impressive instruments being planned for the current suite of 8m telescope, JWST and future extremely large telescopes.

A plan of the report follows. In §2, we make some remarks about the remarkable way in which UKIRT has successfully adapted to the changing nature of infrared astronomy over the years. Occupying its unique vantage point on possibly the world's premier accessible site for infrared astronomy, we list some unique aspects concerning the facility and its operations. In §3 we review the current state of UKIRT; we assess its diverse set of instruments, innovative features regarding its operation and its scientific productivity on a global scale. §4 covers the `UKIDSS-era' just commencing. Since this project will be reviewed independently, we make specific suggestions concerning the optimum balance between survey and non-survey science and address a perceived confusion within the UK community concerning the relative roles of WFCAM on UKIRT and the more powerful infrared capabilities of the 4m VISTA telescope nearing completion at ESO. To address the long-term role of UKIRT, in §5 we first assemble the likely state of play in terms of infrared facilities accessible to UK astronomers. Although several UK individuals have already proposed interesting instrumental initiatives for this era, the panel decided, after much discussion, not to rank these at this stage. Instead, we comment on each and propose a specific path for evaluating these and other ideas during the next 2-3 years. In §6 we raise some strategic issues for consideration by PPARC. In §7, we summarize our conclusions and give strong support for the key role that UKIRT has played and, we believe, can continue to play for at least the review period.

2. The Changing role of UKIRT

The UKIRT `story' is a truly remarkable one. Initially conceived as a dedicated infrared `light bucket' on a site with low mean water vapor content, following many improvements to the facility, its imagers now routinely achieve an image quality of better than 0.5 arcsec FWHM at 2 microns. For many years, infrared detectors lagged their optical counterparts, but at last panoramic imaging capabilities are available at near-infrared wavelengths and, via WFCAM and its associated optics, UKIRT represents the current frontier.

However, the pace of change in infrared astronomy is relentless, both technically and in scientific scope. High order adaptive optics (AO) corrections are now being routinely achieved on several 4-8m telescopes, some equipped with lasers. This is providing near-diffraction-limited performance and dramatic discoveries. Indeed, much of the time on the largest telescopes now involves imaging and spectroscopy of targets where superlative image quality is at a premium. Moreover, dedicated airborne and space facilities are now eroding UKIRT's mid-infrared capabilities. An 80cm facility such as Spitzer can, albeit with low angular resolution, achieve much deeper images at 3-8μm than any ground-based facility.

Despite the arrival of larger aperture telescopes, it is important to recognize that 4m's have a strong and continuing role in the 8m era. Observing time is always competitive and limited on the largest facilities, which, in the case of Gemini and the VLT, the UK shares with many other nations. Moreover, 4m's can very effectively synergize with their more powerful counterparts. A classic example is the continuing partnership between the Palomar 5m and the Keck 10m; survey imaging on the former continues to provide targets for deep spectroscopy on the latter. Via instrumental developments, 4m telescopes can also address specific scientific questions. Perhaps the best example is the 2dF facility on the AAT where, via a modest capital investment (on the scale of that required for a new facility), a wide-field spectroscopic instrument generated a self-contained galaxy and QSO survey, which has made the AAT the most-cited telescope in its class. The required wide field could not have been provided on a larger telescope and so the AAT has moved into a natural `niche' of its own.

Although WFCAM offers UKIRT an immediate analog to 2dF at the AAT, there are some differences. The only competitor to 2dF was the dedicated 2.5m Sloan Digital Sky Survey facility. However, the WFCAM is being chased by comparable facilities at CFHT, KPNO and ultimately, at VISTA (Table 1). If UKIRT is to follow the AAT's example and dedicate itself largely to `campaign mode science', can it remain competitive in the short-term and are there other niches it could occupy in the future?

In considering the changing nature of infrared astronomy and the present and future role of UKIRT, it is helpful to list some of the unique features the facility offers to the UK community.

- It is located on Mauna Kea, the premier infrared site in the Northern hemisphere, alongside other facilities (JCMT and Gemini) in which the UK has a major investment. Already a cost-effective synergy in operation has been developed with JCMT and further cost-effective scientific partnerships with Gemini-N and Subaru could be developed in the future.
- It has a remarkably flexible suite of high quality instruments, which, with a few exceptions, can be switched at short notice to take advantage of changing conditions. An impressive operational system has been developed to take advantage of this unique capability and its productivity has been effectively demonstrated.
- Some of the instruments are amongst the most powerful worldwide on a telescope of this aperture. UKIRT currently has the largest near-ir survey camera (WFCAM) and an impressive high-resolution 1-5μm spectrograph with an efficient polarimetric capability.
- The facility is scheduled in such a way that it provides a very valuable role in training the future generation of UK observational astronomers
- As a fully UK-owned facility, complex treaties or the involvement of another partner do not encumber its future.

3. The Present State of UKIRT

The panel reviewed the current operations, performance and instrument suite at UKIRT. Our assessment is based on statistical data provided by the Head of Operations and a tour of the facility during the panel's visit. In general terms, the panel concludes that UKIRT remains a scientifically highly productive telescope and, operationally, a model facility where many innovative ideas have been very successfully put into practice.

As discussed in §2, the instrumentation suite is highly integrated enabling a versatile approach to scheduling. Convincing what can only have initially been a skeptical UK community of the merits of flexible scheduling is in itself a major achievement. The panel was presented with convincing evidence that highly-ranked proposals are completed more effectively via this approach than with traditional scheduling and community support for this model was evident at the Birmingham meeting.

UKIRT has also made great progress via the provision of an online data processing system (ORAC-DR) for most of the instruments offered. This enables observers to immediately process their date (or those of investigators whose programs they are executing) enabling a rapid turn-around in scientific programs.

Perhaps the most interesting observations made by the panel relate to the fact that many experienced UK Gemini users still come to UKIRT to do frontier science. Moreover, many young students and postdocs gain essential training by agreeing to undertake service observing as part of the flexible scheduling program.

The panel's only concern regarding the current state of the observatory is the lack of success in reducing the thermal emissivity. A substantial fraction of science programs continue to be done at thermal infrared wavelengths, yet UKIRT's emissivity (>10%) is comparable to that for non-specialized telescopes. For a facility dedicated to infrared operation this seems surprising, particularly given the proximity to the Gemini – a pioneer in silver coated optics.

The panel considered two studies of the scientific productivity of UKIRT. One, quoted by the Head of Operations in his report (Trimble, Zaich & Bosler 2005, PASP **117**, 111) presents a brief snapshot of various observatory publications in 2001. Its utility is that the results can be compared to a similar snapshot undertaken around ten years earlier. The survey attempts to address the question of whether 4m science is becoming less interesting now that 8-10m telescopes are in operation. In fact, UKIRT fares remarkably well, demonstrating a steady level of refereed output since 1991.

The second study is a compilation of the number of highly cited papers for the period 2000-2004 (Benn et al, **http://www.ing.iac.es/~crb/cit/9903_prelim.html**). This is more useful in comparing the recent productivity of UKIRT to other facilities. Of particular interest is the fact that UKIRT's impact over this period is double that of the IRTF, the other dedicated infrared facility on Mauna Kea. As expected, the AAT citations are swelled enormously by the huge impact of the 2dF surveys (registering an impact factor 4 times that of UKIRT and WHT, which are broadly the same). Indeed, the AAT experience gives strong justification for the transition to campaign mode science now enabled at UKIRT with WFCAM and UKIDSS.

It is very hard to select a few recent science highlights from the many articles of high impact based on UKIRT data, but the panel was greatly impressed by its role in (i) charting the fundamental physical properties of late M and L dwarfs, (ii) multi-wavelength studies of high redshift quasars and (iii) diagnostic studies of sub-millimetre sources and (iv) ionization studies of molecules in diffuse interstellar clouds.

UKIRT operates with about 30 FTE and its operations budget (currently $3.08M) has been decreasing since 2000. Noting access provided to the University of Hawaii, this is equivalent to about $10K per UK night which the panel considers to be a low figure in comparison to other facilities of equivalent productivity. Mauna Kea is an expensive location and consequently the observing and maintenance programmes must be well run, The fact that, over this period, UKIRT invested both in preparing for Michelle and WFCAM and developing innovative operational concepts such as flexible scheduling, is a testament both to the observatory's efficiency and the quality of its management staff.

4. The Role of UKIRT during 2005-2010 *(the `UKIDSS-era')*

During the panel's tour of UKIRT, the WFCAM instrument made a profound impression. Its scientific potential, technical scale and engineering requirements are each comparable to those of the highly successful 2dF facility at the AAT. The panel was also impressed with the level of preparedness at JAC for its exploitation. At various levels, the observatory staff are clearly committed to making a seamless transition to a new era of campaign mode observing.

The panel strongly endorses the scientific promise of WFCAM and the UKIDSS program, the backbone of WFCAM science for the next few years. This is an ambitious step and a tremendous opportunity for the UK. As the UKIDSS program will be independently reviewed in around 2 years time, the panel offers the following comments which may be of interest in planning that review.

In brief, these suggestions are:

- The diagnostic role of instruments other than WFCAM should be regularly reviewed. In particular, the panel believes UKIRT's 1-5μm high-resolution spectroscopic instrumentation is a vital capability which should be retained for as long as it is scientifically productive. The observatory has a broader community than that concerned with survey imaging which needs to be retained through the UKIDSS campaign.

- While it is clearly important to undertake a significant WFCAM survey such as UKIDSS, the panel considered it equally important to regularly monitor the fraction of *non-UKIDSS* time made available with the instrument so as to ensure a natural tension with new proposals. At present only 20% of the WFCAM time is set aside for non-UKIDSS use. Ensuring some flexibility to establish the right balance is important.

- The panel was unclear on the requirements for following up the UKIDSS images. Will the UK's access to Subaru's FMOS, Gemini's NIRI and GMOS be adequate for full exploitation of the survey? This should be a clear item in evaluating the scope and continued promise of UKIDSS.

- For how long will WFCAM remain unique? Table 1 summarises the current state of panoramic imaging cameras on various telescopes. Although the CFHT and KPNO telescopes must serve both optical and near-infrared users, the WIRCAM and NEWFIRM cameras arriving shortly on those respective facilities will clearly be competitive. And when VISTA arrives at ESO there will be a powerful facility in the southern hemisphere. The panel learned that plans for the scientific exploitation of VISTA are still at an early stage and thus concluded the UK could play a leading role in establishing the appropriate synergy between UKIRT and VISTA. It firmly believes there is a strong case for both northern and southern facilities of this kind given the potential connections with facilities at other wavelengths (e.g. ALMA in the south, VLA and LOFAR in the north).

Table 1
Current & Projected Near-IR Survey Facilities

Telescope	***Camera***	***Field (deg^2)***	***Pixel (arcsec)***	***Commissioned***
Hale 5m	WIRC 2K	0.021	0.25	2000
UH 2.2m	ULBCAM 4×2K	0.08	0.25	2002
UKIRT 3.8m	WFCAM 4×2K	0.20	0.40	2004
CFHT 3.6m	WIRCAM 4×2K	0.11	0.30	2005
KPNO 4.0m	NEWFIRM 4×2K	0.25	0.40	2006
VISTA 4m	16×2K	0.57	0.35	2008?

5. The Role of UKIRT after 2010 (*the `post-UKIDSS era'*)

We now turn to the role of UKIRT during the era beyond that when the UKIDSS program is considered to be complete. In its deliberations, a precursor question the panel considered is what infrared capabilities will the UK community likely have access to, say, in 2010? In Appendix IV we summarize the projected list of infrared instruments and their capabilities on those telescopes in which the UK is a partner as well as those on other telescopes. In considering any future role for UKIRT, balancing its long-term science niche alongside these capabilities is essential.

At the Birmingham community meeting it became clear that the UK community has already begun to consider scientific opportunities for UKIRT in this era. A wide range of ideas, some involving new instrumental initiatives, were presented and discussed. The panel found many of these ideas, as documented in the paper *UKIRT: Instrumental Options*, very exciting. At this early stage, their technical feasibility and financial requirements need further work. Nonetheless the panel strongly endorses the concept of evaluating these (and other ideas) given their scientific potential.

The panel selected a number of these directions for further scrutiny and, below, we briefly comment on the scientific and technical merit of each proposed capability alongside those coming online on larger telescopes (Appendix IV). We then recommend an approach to PPARC for a more rigorous evaluation of these and other opportunities.

5.1 Further Imaging Surveys

The completion of UKIDSS will represent a major achievement for UKIRT. Despite the large investment of time, there will be a continuing need for large-scale wide-field near-infrared imaging surveys in the northern hemisphere.

The UKIDSS Large Area Survey (LAS) is well matched in depth ($K_{AB} \sim 20.2$) to the Sloan Digital Sky Survey (SDSS) but covers less than half of the SDSS area below $\delta = 60^o$. Completion of the remaining area to this depth would be an attractive long-term legacy for the UKIRT and the UK astronomical community. Given the UKIDSS data pipeline and UKIRT's low cost operations, it is likely that UKIRT would be the most cost-effective facility to undertake this program, which also takes advantage of the natural quality of the Mauna Kea site. Such a program would be complementary to the more expensive satellite surveys planned at $\lambda > 3$ μm (e.g. the NASA WISE mission) and since the main SDSS area is in the north, could only be partially undertaken with VISTA.

Given the large fraction of UKIRT time devoted to UKIDSS, there is also likely to a pent-up demand for wide field imaging studies that will not have been satisfied by the various UKIDSS surveys. Obvious examples include searches for transient sources, narrow-band imaging, and observations of non-UKIDSS deep survey fields. As infrared array technology develops, it would be attractive to upgrade WFCAM if a further emphasis on wide field imaging at UKIRT was foreseen. There appear to be no technical reasons why an almost fully covered focal plane of 9×2K 3-side buttable detector arrays could not be achieved in the current WFCAM, offering a two-fold gain in imaging speed.

5.2 Adaptive Optics (AO) Applications

As a telescope of diameter D has $\sim(D/r_0)^2$ coherent phase patches, where r_0 is the Fried parameter, an AO system for a 4-m telescope can be considerably simpler than one for an 8-m, and a given system will provide better wavefront correction on a smaller telescope. As $r_0 \propto \lambda^{6/5}$, AO system performance increases and complexity decreases with increasing wavelength. Good seeing is characterized by large r_0, so it is preferable to deploy AO systems on sites like Mauna Kea that offer the best intrinsic conditions. These factors suggest that AO systems for UKIRT should be given full consideration.

Ground-layer AO (GLAO) systems are simple to construct, may not require a laser guide star and are particularly effective for the study of small (~0.1 arcsec) extended objects, e.g. high redshift galaxies, well matched to the corrected beam size. Although only a single low-level layer is addressed, the correction is valid over much larger field angles than conventional AO. The reduction of the sky background afforded by improved angular resolution means that GLAO has the potential to speed up deep surveys by a factor of ~ 5 or increase the depth by about 1 mag.

GLAO can only be effective if a significant fraction of the seeing accumulates in the lower atmosphere ($h << 5$ km). A dedicated program that measures the vertical turbulence profile (i.e., $C_n^2(h)$) and wind speeds must be instituted to evaluate the potential of GLAO for UKIRT and to enable the system design. The panel noted that the Gemini Board has recently agreed to make such measurements on Mauna Kea and thus there is an opportunity for synergistic exchange between the two observatories.

Mid-infrared AO:. Poor knowledge of the point-spread function (PSF) is the primary systematic error associated with AO observations. On a given night the performance at near-infrared wavelengths may change unpredictably as conditions vary. However, the effect of these limitations decreases with increasing wavelength. For example, a wavefront error of 220 nm rms corresponding to a Strehl ratio of 0.5 at H band (1.65 µm) is equivalent to one of 0.98 at 10 µm. Although a larger telescope may have a smaller diffraction limit, the signal/noise at the corresponding spatial frequency may be poor if the Strehl performance is low. A small telescope can outperform a larger telescope at angular frequencies ~ λ/D if it is equipped with a sufficiently high-order AO system.

High fidelity imaging with very high Strehl ratios (> 0.9) at thermal infrared wavelengths enables a broad range of science programs. For example PSF stability enables a broad range of science associated with the circumstellar environment, including circumstellar and debris disks, circumstellar envelopes of evolved stars, and cool or dust-enshrouded companions.

5.3 Wide Field Spectroscopy

The UK has pioneered wide-field multi-object spectroscopy on many of its well-established facilities (AAT, UKST, WHT) and so it is natural to consider the merits of extending the newly-found wide-field imaging capability of UKIRT from one of imaging (with WFCAM) to multi-object infrared spectroscopy. Of the ideas presented at the Birmingham community meeting, the concept of a UKIRT wide-field spectroscopic capability (WFSPEC) perhaps received the most attention.

The scientific motivation for such an instrument is worthy of further consideration. Via the implementation of WFCAM, UKIRT now has a ~1 deg^2 field and, within such a large field, there would be an abundance of accessible Galactic and extragalactic sources for spectroscopic study. At moderate spectral resolution (R~4000), radial velocities would yield membership for various stellar systems located by UKIDSS and, more ambitiously, redshifts for infrared-luminous galaxies located by SCUBA2. At higher spectral resolution (R~60,000), molecular studies might be practical in protostellar sources.

Multi-object near-infrared spectroscopy is a rapidly developing territory so this is a very timely consideration. Strategically, most effort is being directed to deep multi-slit or multi-IFU studies of very faint galaxies over modest fields (5-10 arcmin) on 8-10m class telescopes. Only the FMOS spectrograph, which samples the 0.25 deg^2 prime focus of Subaru, is addressing highly multiplexed, wider field applications. The key question, therefore, is the degree of complementarity between this facility (being commissioned in 2005) and a future facility at UKIRT.

Two technical innovations could give UKIRT an advantage over FMOS. First, both the fiber positioner and spectrographs of FMOS are optimized for operation in the J and (partly) H bands. To cryogenically cool FMOS so as to enable operation through to 2.5μm was considered too complex and expensive. Secondly, as with almost all current infrared spectrographs, in FMOS OH suppression is implemented in software. By adopting a sufficiently high spectral resolution (R~4000), the OH spectrum can be partially resolved and faint spectral features can be optimally located. However, the latter technique is very expensive in detector acreage - the limiting factor in governing the multiplex gain. If OH suppression could be implemented in the hardware, there would be a significant improvement in the effectiveness of a wide-field instrument.

Hawarden and Henry have proposed an interesting concept, based on an idea developed at the AAO, for OH suppression via fiber Bragg gratings. The panel was somewhat skeptical of this development given it has not been demonstrated for the multi-mode fibers used in multiple object spectrographs, but, as with all new developments, felt it was definitely worthy of further consideration. Alongside the technical challenges, the main question for the UK community to consider is the degree of complementarity with wide-field infrared spectrographs on larger telescopes. Although Subaru+FMOS is the only currently funded example sampling a field comparable to UKIRT, the science case for a UKIRT facility should be independently compelling and self-sufficient.

5.4 Radial Velocity Surveys for Exo-planets

The search for planets with masses approaching that of the earth is one of the most fundamentally important and rapidly advancing frontiers of modern astrophysics. As evidenced by the recent Keck discovery of an 8 M_{Earth} planet, radial velocity (RV) measurements can now be performed with the precision necessary to discover such planets around low-mass stars.

The goals are to now push down to even lower masses, and to establish the statistical prevalence of such planets, in particular within the habitable zone. This is an area in which 4-m telescopes can make an immense impact given sufficient allocations of dedicated time, as evidenced by the 500-night HARPS project now underway at ESO on the 3.6-m telescope at La Silla. Moreover, and most crucially for UKIRT, it is also a field which is best pursued in the near-infrared because current optical studies (e.g. HARPS, and the N2K Keck+Magellan+Subaru project) are limited to bright optical magnitudes, $V < 11$. At such optical limits there are only ~700 M dwarfs in the whole sky, whereas to an infrared magnitude limit of $J < 11$, there are ~30,000. Moreover, to achieve the detection of planets with a mass equal to the earth within the habitable zone, one must observe stars of stellar type M8 or later, for which a meaningful sample is not possible at $V < 11$.

It is clear, therefore, that a major (100-200 night) RV survey (using a dedicated J+H-band high-stability, bench-mounted spectrograph) for planets around M-L dwarfs could be an attractive and exciting project for UKIRT. It would also be of enormous strategic value for UK science, by efficiently facilitating high-profile UK involvement in the burgeoning exo-planet field. The only other observatory considering building such a dedicated instrument is Gemini North. Here UKIRT could play a key role either by building its own instrument, or by sharing such a spectrograph (perhaps via 300-m fibres) with Gemini in a joint campaign.

Studies suggest the necessary 1 m s^{-1} stability is achievable although many technical challenges need to be overcome. Specifically, the detection of earth-mass planets in the habitable zone around M dwarfs requires the development of radial velocity standards (equivalent of the I_2 absorption cell, candidates include HCN and C2H2). Contamination by OH airglow and terrestrial H_2O and CO_2 absorption may be problematic. Finally, stellar activity, rotation and dust may affect the precision. Despite these qualifications, the potential rewards of success are enormous both for UKIRT and for UK science. A joint campaign with Gemini may help both to mitigate risk, and to facilitate a long-term observing campaign capable of covering a range of stellar brightnesses with good temporal sampling.

5.5 Thermal Infrared Applications

The thermal infrared spectral region is currently receiving renewed attention as Spitzer probes faint objects at these wavelengths for the first time. Current space missions and those planned for launch in the remainder of the decade enjoy the benefits of a low background but suffer from the relatively coarse diffraction-limited spatial resolution compared to that achievable with large aperture telescopes on the ground. Not until JWST is launched in 2012 will a space mission provide both high sensitivity and high spatial resolution.

In addition to Spitzer, which is currently conducting a variety of imaging and spectroscopic observations, the ASTRO-F and WISE satellites are scheduled for launch in early 2006 and 2008 respectively. Both missions will survey the whole sky at thermal infrared wavelengths. The Japanese ASTRO-F mission has a 70cm telescope and a projected lifetime of ~550 days, of which the first third will be dedicated to an all-sky survey at 9, 20, and 50-180 microns, with resolutions of ~4 arcsec in the mid-IR and 40-80 arscec in the Far-IR. Pointed observations will allow more photometric bands to be used and low resolution spectra (R<50) to be obtained. The NASA WISE mission will survey the whole sky in four photometric bands at 3.5, 5, 12 and 23 microns in its 8-month mission. It has a 40-cm telescope and re-imaging optics giving 6" FHWM resolution (diffraction-limited to 12" at 23 microns). Mid-IR instruments on 8-m ground-based telescopes provide high spatial resolution and relatively high sensitivity for observations of compact objects, but over very small fields. VISIR and Michelle allow spectroscopy at much higher spectral resolution than planned from space.

However, space missions may not be able to survey the brightest regions in our Galaxy (e.g. the Galactic plane) or nearby bright objects because of limitations from saturation or dynamic range. As the brightest and nearest objects are likely to be those in which structure can be resolved, there is a potentially strong case for a new AO-fed ground-based instrument to exploit UKIRT with high spatial resolution and very high PSF stability.

The panel noted that UKIRT currently offers comprehensive instrument coverage in 1-5μm region, including imaging, spectroscopy and polarimetry. It is possible that as HAWK-I and KMOS replace ISAAC on the VLT, the ESO capabilities at 3-5μm will be restricted to those offered by NAOS-Conica, while the Gemini capabilities will depend on GNIRS and the long-term plans for NIRI. Whilst 1-2.5 μm IR instruments are widely available, the same is not true at 3-5μm, and the continuing availability of these capabilities at UKIRT will remain important.

5.6 Recommendations

It is clear from the above discussion that there are several exciting niches for UKIRT in the future, although none of the ideas presented to the panel has yet been developed to the point where it can be rigorously evaluated technically or financially. Although not all of these initiatives need necessarily wait for the completion of the UKIDSS program, the panel considered there is sufficient time, during the UKIDSS era, for a proper planning exercise to address these questions.

The panel thus proposes that PPARC invites, perhaps via the UKIRT Board, an invitation for ambitious 3-5 year observing campaigns requiring several hundred nights of UKIRT time to address fundamental high impact science questions. These proposals could include science cases based on exploiting existing instruments (including WFCAM) as well as the option for funding studies of new instrumental initiatives. Conceivably, the five cases studied here could be presented as examples, but it will also be important to explicitly encourage other, new, possibilities. Certainly the panel stresses the need for examining the current set of ideas more carefully.

Criteria for evaluating these proposals should include:

- Scientific merit: what are the fundamental science questions to be addressed
- Complementarity and synergy with other facilities (see Appendix IV): will UKIRT fill a useful niche?
- Considerations of design and feasibility
- Timeliness and cost
- Strategic relevance for the UK comunity

6. Strategic Issues

We finally make some general remarks on the strategic importance of UKIRT as a scientific facility on Mauna Kea.

UKIRT is significant in being a UK-owned facility on the premier northern hemisphere site and so has, in the panel’s view, much greater long term value than, for example, a UK presence on Siding Spring or even the Roque de los Muchachos at La Palma. The UK has built up an enviable reputation for innovative and cost-effective operations on Mauna Kea.

The panel also believes that there are more opportunities for scientific and operational synergy with Gemini-North, than is currently the case. Gemini has just completed most of the initial commissioning tasks and is entering a more routine operational phase, while UKIRT is moving largely into campaign mode science. With the change of Directorship at Gemini, the panel urges PPARC to consider how to better coordinate its facilities on Mauna Kea.

By the time key decisions need to be taken on UKIRT’s long-term role, the future of large telescope development on Mauna Kea might be known. The US-Canadian Thirty Meter Telescope project currently aims to make its site decision in late 2007/early 2008 and, naturally, Mauna Kea is a strong option. Better synergy between the TMT partners’ existing facilities is already being discussed as a logical way to reduce long-term operational costs. The UK’s stake in UKIRT might be leveraged advantageously in these deliberations.

7. Conclusions

In summary, the panel concludes that UKIRT remains a remarkably productive and cost-effective facility. As a dedicated infrared telescope of the 4-m class it remains the most productive worldwide and, via the onset of the UKIDSS campaign, it is poised to undertake several ambitious surveys, which will raise the UK science profile considerably. We make some suggestions for how the UKIRT Board and subsequent reviews of the UKIDSS survey might monitor the survey progress and safeguard some flexibility in the optimal use of UKIRT.

Beyond the UKIDSS campaign, the panel discussed several routes for continued excellent science with UKIRT. These are sufficiently promising that we recommend PPARC instigate a call for proposals and a period of technical and financial evaluation prior to a decision on the way forward according to a set of suggested criteria.

UKIRT remains a truly remarkable facility. It has transformed its capabilities on several occasions and can do so again. Strategically, it is a very important facility on the world’s premier northern hemisphere site and of great value to the UK community.

Appendix I

Panel Membership

Richard S Ellis (Caltech) (Chair)

Simon J Lilly (ETH)

James R Graham (UC Berkeley)

James Dunlop (University of Edinburgh)

Harvey Richer (University of British Columbia)

Patrick F Roche (University of Oxford)

Timeline:

April 4th 2005: Ellis attended the meeting "UKIRT: Future Science and New Instrumentation" at the Birmingham National Astronomy Meeting: April 4th 2005

June 8th 2005: Telecon to review Birmingham meeting, Board and Observatory material

June 26-27th 2005: Visit to JAC, tour of UKIRT, discussions with key staff and agreement on structure of report

July 22nd 2005: Telecon to review draft report

August 30th 2005: Report submitted to UKIRT Board

September 9th 2005: Presentation to UKIRT Board

Appendix II

Terms of Reference

The UKIRT Board wishes to set up a Review Panel to review the UKIRT Telescope on Hawaii in order to provide an international and independent perspective on its likely scientific programme and strategic direction over the next ten years The Review Panel will make recommendations to the UKIRT Board and through it to the Head of UKIRT Operations and PPARC.

UKIRT is operated by the Joint Astronomy Centre (JAC), which also operates the James Clerk Maxwell Telescope (JCMT) under a TriPartite agreement with The Netherlands and Canada. It is intended that a parallel review of the JCMT will be convened on the same time scale. The interdependence of present operations need not be a constraint on recommendations for future operations.

The Review Panel is asked to:

1 Consider the astronomical role of UKIRT in the next ten years and beyond, with particular attention to its competitive international position in the context of other telescopes with infrared capability.

2 With respect to the above:
  2.1 consider the scientific productivity and international competitiveness of UKIRT in the context of its previous record and future potential;
  2.2 consider options for development of the facility, commenting, if appropriate on modes of operation, time allocation, and the level of user support.

3 Having undertaken 1 and 2, produce a written report to the UKIRT Board, to include recommendations for the future, to guide PPARC in its strategic planning.

The Review Panel shall comprise a chairman and up to four members of international astronomical distinction and experience, membership to be agreed by the UKIRT Board, in consultation with the Panel chairman. PPARC will provide administrative support as required, but it will be expected that the Panel will be responsible for drafting its own report. The Panel's work should be planned so as to be able to report to the September 2005 meeting of the UKIRT Board.

Appendix III

Panel Documentation

- UKIRT's Current and Future Strengths (supplied by the UKIRT Board as part of the review material)
- UKIRT Operations: A Current Status Document (supplied by A Adamson as part of the review material)
- UKIRT Instrumental Options: Design Studies and Discussion (collated by A Adamson on the basis of material presented at the Birmingham meeting and presented to the panel)
- UKIRT Infrared Deep Sky Survey (UKIDSS): Information note supplied by Prof A Lawrence and Dr S Warren following email correspondence with the Chair.
- A Ground Layer Adaptive Optics System for UKIRT (Dr P Lucas, U Herts): Birmingham powerpoint presentation and further information as requested by panel.
- Seeing Statistics at the Upgraded 3.8m UKIRT (Seigert et al, astro-ph/0208448)
- UKIRT Top-Cited Papers 2000-2004 (supplied by A. Adamson following a request by the panel)
- Existing Collaborations between UKIRT and other Mauna Kea Telescopes (supplied by Dr G. Davis after a request by the panel)
- Scientific Impact of Telescopes Worldwide 2000-2004: compilation by Chris Benn (supplied voluntarily to the panel by Dr Benn)
- Future of UKIRT: Input from Prof. R Joseph (IfA) following consultation with IfA faculty (following a request from the panel)

Appendix IV

Infrared Capabilities Available to UK Astronomers

Facility	NIR imaging	NIR spectra	MidIR imaging	MidIR spectra	AO-fed
8m Gemini-N	NIRI 1-5 mu; 0.13 – 4.0 sq. arc min; 0.022 – 0.117 arcsec/pixel	NIRI 1-5 mu; long slit; R=450-1300			Yes - Altair
8m Gemini-N		NIFS 1-2.5 mu; 3 arcsec FOV; IFU R=5000 (2006)			Yes - Altair
8m Gemini-N			Michelle 7-26 mu; 0.21 sq. arc min; 0.099 arcsec/pixel	Michelle R=100-30,000	No
8m Gemini-S	Flamingos-II 0.9-2.5 mu; 30 sq.arcmin; 0.18 arcsec/pixel (2006)	Flamingos-II 0.9-2.5 mu; 2 x 6 arcmin; R = 1300-3000; multi-object (2006)			Yes - GSAOI
8m Gemini-S		GNIRS 1-5mu; long slit; R= 1700-18,000; IFU 5 arcsec			No
8m Gemini-S			T-ReCS; 8-26 mu; 0.17 sq. arcmin; 0.09 arcsec/pixel	T-ReCS R=100-1000	No
8m Gemini-S	NICI 1-5 mu; coronagraph; 0.018 arcsec/pixel (2006)				Yes - Dedicated
8m Gemini-Future	GSAOI 0.9-2.4 mu; 1.4 sq. arcmin; 0.02 arcsec/pixel				Yes
8m Gemini-Future	EXAOC 1-2.5mu 2 arcsec FOV (2009)	EXAOC 2 arcsec IFU R=40 (2009)			Yes
8m Gemini-Future		HRNIRS 1-2.5 mu; R<80,000 (2009+)			
8m VLT	ISAAC 1-5mu 2.5 arcmin FOV	ISAAC 1-5 mu R<3000			No
8m VLT		SINFONI 1-2.5mu; IFU 0.8-8 arcsec FOV; 0.025-0.25 arcsec/pixel; R=1500-4000			Yes
8m VLT	Hawk-I 0.85-2.5 mu; 56 sq. arcmin FOV; 0.1 arcsec/pixel; (2007)				

8m VLT		K-MOS 1-2.3 mu; 24 IFUs 7.2 arcmin; R<4000 (2010)			
8m VLT			VISIR 8-24 mu; 19-32 arcsec FOV; 0.075-0.13 arcsec/pixel;	VISIR R=350-25,000	No
8m VLT		CRIRES 1-5 mu; 50 arcsec slit length R=20,000-100,000 (2006)			
8m VLT	NAOS-CONICA 1-5 mu; 0.007-0.87 sq. arcmin FOV; 0.013-0.054 arsec/pixel	NAOS-CONICA 1-5 mu; R=400-1500			Yes - NAOS

Upcoming Non-UK IR facilities

Facility	**NIR Imaging**	**NIR Spectra**	**MidIR Imaging**	**MidIR spectra**	**AO-fed**
10m Keck		OSIRIS IFU 1-2.5mu R=3800			Yes
10m Keck	NIRC2 1-5 mu; 0.02-0.35 sq.arcmin FOV; 0.01-0.04 arcsec/pixel	NIRC2 R<5000			Yes
10m Keck		MosFire 6 arcmin R=4000			
8.4m Subaru	IRCS 1-5mu; 0.15-1.0 sq. arcmin; 0.022-0.059 arcsec/pixel arcsec	IRCS R=100-2000			Yes
8.4m Subaru	CIAO Coronagraph 1-2.5 mu; 0.039-0.132 sq. arcmin FOV; 0.01-0.02 arcsec/pixel				Yes
8.4m Subaru			COMICS 7-25 mu; 0.37 sq. arcmin; 0.13 arcsec/pixel	COMICS R=250-10,000	
8.4m Subaru	MOIRCS 1-2.5mu	MOIRCS 1-2.5mu			
8.4m Subaru		FMOS 1-1.8mu 30arcmin 400 fibers R<5000			
10.4 GTC	EMIR 1-2.5mu 6 arcmin 0.2arcsec/pixel	EMIR R<4000			
10.4 GTC			CanaryCam 30 arcsec FOV; 0.1 arcsec/pixel	CanaryCam R<1000	