The UKIRT Upgrades Programme: Preparing for the 21st Century

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ABSTRACT

In the 1970s the pioneering thin-mirror 3.8m United Kingdom Infrared Telescope (UKIRT) of the UK Science and Engineering Research Council (SERC) was conceived as a low-cost “light bucket”, with an 80% encircled-energy (e-e) diameter ≤ 3”. However the delivered primary mirror had an 80%encircled-energy diameter of ~ 1” and the telescope has regularly delivered sub-arc-second images. To exploit this quality and to keep UKIRT competitive in a 21st century of 8-meter telescopes, in 1991 the SERC initiated an ambitious Upgrades Programme, with the goal of routinely providing near-diffraction limited images at 2.2 microns. The major elements of the program are an adaptive tip-tilt secondary system, an active five-axis secondary collimation system, an upgraded primary mirror support system providing active control of the main optical aberrations, and modifications to the telescope and its enclosure to reduce or eliminate dome and mirror seeing, so as to take advantage of the excellent natural seeing on Mauna Kea. This paper outlines the overall project goals, the proposed strategies for upgrading the telescope and the progress to date.

1 INTRODUCTION

The UK Infrared Telescope was originally conceived as a large, low cost, lightweight telescope, based on the 1.5 m Flux Collector on Teneriffe, now the Carlos Sanchez Telescope of the Instituto de Astrofísica de Canarias (IAC), which was designed in the 1960s by John Long and Prof. Jim Ring of Imperial College, London (ICSTM). For UKIRT the design was further developed by the main contractors, Dunford Hadfields, in conjunction with the optical contractor, Grubb Parsons.

At the latter company the late David Brown pioneered the development of techniques for figuring thin flexible primary mirrors, now in widespread use. These techniques proved successful, and, when the surface figuring had been completed, the UKIRT primary mirror was capable of delivering an image with 80% e-e diameter ~ 0.″9 (Humphries, 1978) corresponding to a FWHM of less than ~ 0.″4, notwithstanding its exceptionally thin design, less than half the thickness of a traditional mirror.

Over the 15 years since its commissioning UKIRT has been improved in many ways. For a decade the tracking and pointing performance has been an order of magnitude better than originally specified. In 1988 we began
framing a programme to enhance all other performance aspects, but especially the image quality delivered to users, to match these gains. In 1989 careful optical adjustments reduced the image FWHM at $\lambda = 2 \mu m$ from $\sim 1''2$ to $\sim 0''6$ in good seeing, and in 1990 images with FWHM $\sim 0''4$ were indeed secured, albeit with exposures of only 160 ms. In 1991 the overall programme was partially funded by the SERC and a collaboration with the Max Planck Institut für Astronomie (MPIA) in Heidelberg was initiated, leading to a formal agreement in October 1993 that the MPIA would contribute several major elements to the development programme.

2 PROJECT GOALS

Conventional models of atmospheric effects based on Kolmogorov turbulence theory predict that in the near-IR ($\sim 2 \mu m$) simple tip-tilt corrections applied to stabilise the images of a 4 m telescope like UKIRT should produce resolution within about a factor of 2 of the diffraction limit (see, e.g. predictions by Roddier et al. (1991) for a 3.6 m telescope). This implies that an optically-perfect UKIRT with tip-tilt correction should be able to deliver images with FWHM of $\sim 0.25$ arcsec (Strehl ratio $\sim 0.25$) in typical Mauna Kea seeing. This in turn suggests the numbers that we have adopted as the overall programme REQUIREMENT:

- The telescope systems, without atmospheric effects, MUST be capable at all times of delivering images with FWHM at $\lambda \sim 2.2 \mu m$ of not more than $0''.25$, and a Strehl Ratio not less than 0.85.

However, if this specification is just met and no more, the angular resolution of the combined telescope and atmosphere will be degraded by a factor of $\sim \sqrt{2}$ and the signal-to-noise by a factor of $\sim 2$. Furthermore there
is some evidence (McKechnie, 1992; Bester et al., 1992) that near-diffraction limited performance at 2 μm or so may be attainable with tip-tilt corrections alone. Again, we would prevent the telescope systems from degrading the possible imaging performance allowed by the atmosphere by any more than $\sqrt{2}$, as above. This suggests a programme GOAL:

- The telescope systems, without atmospheric effects, SHOULD be capable at all times of delivering images with FWHM at $\lambda \sim 2.2$ μm of not more than $0.7''$. 12.

If achieved, this goal would of course preserve almost undegraded the resolution predicted by the conventional atmospheric models after tip-tilt correction. This is a further reason for taking the goal as our working target for the telescope systems error budgets.

While we have believed for some time that small-scale figuring errors on the UKIRT primary mirror are not serious enough to jeopardize this goal, we have been greatly encouraged by the recent demonstration at UKIRT of near-diffraction-limited resolution in the near-IR using the low-order adaptive-optics system of the Institute for Astronomy of the University of Hawaii (c.f. Roddier et al., 1994).

3 TELESCOPE SYSTEMS

3.1 Adaptive Tip-Tilt Secondary System

At the core of the Upgrades is the proposed high-bandwidth tip-tilt secondary mirror system. The conceptual design of the system has been presented by Pitz, Kohloff and Marth (1994) and a more final design is described in more detail elsewhere in these proceedings by Pitz et al. (1994).

The tip-tilt system will be provided by the MPIA and is a ~ 3rd-generation piezo-electrically actuated system from Physik Instrumente (c.f. Pickles et al., 1994, this volume, for a first generation facility just now coming on line). The secondary mirror, ~ 310 mm in diameter, is being fabricated from lightweighted Zerodur by a novel process (c.f. Pitz et al., loc. cit.). The actuation system is specified for a flat servo response up to $> 200$ Hz, and has a high degree of momentum compensation ($\sim 95\%$). It has a maximum throw of $35''$ peak-to-peak with full performance up to 10 Hz chop frequency, and is therefore capable of classical chopped IR observations.

In normal operation the tip-tilt system will correct seeing effects, with optimum yield for a telescope of the size of UKIRT at wavelengths around 2.2 μm, but will also stabilize images which would otherwise be degraded by windshake, a vice to which the lightweight structure and compact dome of our telescope make it peculiarly vulnerable. The fast response time of the secondary and its sensor system (q.v.) will also allow extremely fast and stable nodding manoeuvres, limited only, in fact, by the translation time of the crosshead stage.

As part of the tip-tilt package, and in close collaboration with ROE, the MPIA has designed a new telescope top-end assembly. The system has, in particular, to avoid resonances which might be stimulated by the tip-tilt correction motions of the fast secondary, despite the high level of momentum cancellation. The agreed design uses a single top ring and protruding, untensioned vanes. The latter will be about 16 mm thick and will be equipped with reflective stepped undersurface fittings to reduce emissivity. The new top-end design is expected to offer a significant enhancement of sky coverage in the South, which will be particularly welcome as 6 out of the 40-odd brightest IR galaxies in the sky — including Centaurus A — lie bare degrees beyond UKIRT’s current Southern limit.
3.2 The Tip-Tilt Sensor and Bottom-end Systems

The control of the tip-tilt system is a non-trivial undertaking and has required careful study. Designing the system has been aided by the instrument support philosophy at UKIRT, whereby up to four science/engineering instruments are mounted on an Instrument Support Unit (the ISU) and are fed IR light by a rotating dichroic mirror, which transmits visible light to an acquisition and guidance (A & G) TV below. The latter is supported on a crosshead and can move up to ±4 arcsec from the telescope axis in search of a guide star. A schematic illustration of the bottom-end systems is shown in Figure 2.

The tip-tilt sensor, provided by the MPIA, will be carried on the crosshead along with the A & G camera. An interface unit provided by the ROE will contain one or more (probably selectable) pickoff mirrors close to the focal plane, to feed the signal to the sensor. The latter will be an Astramed CCD system with low readout noise (∼ 3 e−).

Performance of sensor systems for UKIRT is discussed by Glindemann & Rees (1994) elsewhere in these proceedings. These authors address the possibility of sensing and correcting seeing-induced defocus, albeit at the penalty of requiring a brighter guide star, using the proposed UKIRT system. In the basic (quadrant-sensor) operation mode the system bandwidth should be well above 200 Hz.

Consideration has been given to the need to guide on both sides of a chopping cycle. The substantial degradation of the image quality on the unguided side in a single-sided scheme, leading to a loss of essentially all the information in that half of the observing time, inter alia, combined with an expectation that chopping will be popular – and possibly necessary – for some years to come lead us to propose a bottom-end system which can
secondary mirror, which has the effect of reducing the effective aperture of the telescope by at least 15 cm.

4 FACILITY SEEING

Facility Seeing, the deleterious effects on the atmosphere caused by the presence of a telescope and its associated structures, is very topical because of the unprecedented numbers of large telescope construction and development projects under way at the moment.

4.1 Controlling Mirror Seeing

A survey of literature, experience and opinions on Mirror Seeing has been carried out, in order to define targets for a system for its control or elimination. As indicated above, hard information is sparse, but guidelines have been set as follows:

(i) The temperature of the primary mirror MUST not differ from that of the ambient dome air by more than $+1$ C or less than $-3.5$ C. If the primary is warmer than the ambient air (+ve difference) it MUST be ventilated with an average air flow velocity of at least 1 m s$^{-1}$.

(ii) The temperature of the primary mirror SHOULD not exceed that of the dome ambient air and SHOULD not be more than 2.5 C below that of the dome air.

The temperature and ventilation targets will probably be achieved by means of a daytime primary mirror cooling system and a night-time forced ventilation system (the design of the telescope makes natural ventilation of the primary difficult). Despite the intention to control temperatures during the day only, we expect to meet the requirements on a large majority of nights even using the crudest algorithm for predicting the next night’s temperature (“same as last night”). Even the goals will be attainable most of the time, though the occasional large-scale temperature surges which sometimes occur during the night on Mauna Kea will sometimes cause — mostly temporary — violations.

We believe that these precautions will eliminate mirror seeing effects or reduce them to imperceptible levels.

4.2 Controlling Dome Seeing

By Dome Seeing we mean all Facility Seeing effects that are not directly associated with convective effects at the primary mirror. Again, the literature, experience and theory on Dome Seeing has been reviewed; even more so than for mirror seeing, it proves to be sparse and contradictory. For example, we know of serious estimates of the coefficient linking arcseconds of image enlargement to degrees (C) of dome air temperature excess which range from $\sim 0.15$ arcsec C$^{-6/5}$ to at least 0.6 arcsec C$^{-1}$.

We have adopted a coefficient of 0.37 arcsec C$^{-1}$ based on studies by Woolf (1978) normalised to practical experience at the Anglo Australian Telescope (e.g. Gillingham, 1984).

It is even less clear how to quantify the effects of warm and cold local plumes, which can be especially pernicious. The experiments of Murdin & Bingham (1975) indicate a very rough dependence of 3 arcsec per (well-mixed) kW.
Consideration of the telescope performance goals set out earlier leads us to require that the image FWHM be degraded by dome seeing by no more than 0.05", leading for global and local effects to the practical REQUIREMENTS:

(i) The temperature of the dome air in the telescope beam MUST be constrained to differ by no more than 0.13°C from the outside air temperature.

(ii) Discrete sources of cold or hot plumes visible in the telescope beam on Schlieren images MUST be suppressed (i.e. reduced in power to ~ 17 W or less) or dissipated by means of ventilation (~ 1.4 m³ s⁻¹ of cooling air per 100 W of source power).

These requirements appear at first sight to set an almost impossible task of thermal control. However this may not really be the case. The volume of air which concerns us here is simply that in the telescope beam. If we can contrive by ventilation to fill this volume with air at a temperature close to that outside, we will achieve the goal.

In mid-1983 we carried out a thermal audit of the UKIRT dome. We currently believe that about 5 kW of power are being released into the dome air during the night. The dome air has a thermal capacity of 2 x 10⁶ J K⁻¹, so to remain inside our guidelines we must ensure that the dome air is changed every ~ 50 s, about 70 changes per hour if the air is well mixed. This is a large volume of air, but not too daunting when one considers that the area of the smallest aperture which must be present in the UKIRT dome during observing is ~ 20 m². For an aperture of half that area (e.g. two of the ventilation apertures envisaged below), 70 changes per hour will be obtained if the air flow through that aperture averages ~ 5 m s⁻¹, readily achieved on a site with median wind velocity ~ 7 m s⁻¹.

Part of the planned dome work is to decrease the heat leaked into the dome air by improving the insulation of the dome from the lower part of the building. With the removal of heat from systems on the telescope, we believe that a reduction to ~ 1 kW total night-time heat load can thus be achieved. This heat load requires only ~ 14 changes per hour to keep the temperature excess of the dome air below our desired maximum and this can be achieved by a flow through a 10 m² aperture of ~ 1 m s⁻¹. Indeed flow levels not far from this may in any case be induced by the facility ventilation system, which will probably be drawing ~ 10 volumes per hour from the dome at night, simply in order to cool the heat exchangers associated with the building A/C systems and with the closed-cycle coolers used to refrigerate the IR instruments on the telescope.

In order to encourage adequate dome ventilation in most conditions we are proposing to install a number (probably 8) of closable ventilation apertures around the lower dome skirt. These would be ~ 2.4 m square, fitted with doors on the outside for weather protection and fixed or adjustable louvres on the inside to encourage widespread diffusion of the airflow inside the dome. Our current intent is to place ventilation apertures at the bottom of every second gore of the dome shell (Figure 4).

The ventilation doors will be opened and closed so as to maintain an appropriate air flow into or out of the dome slit, depending on the relative wind direction. (It should be noted that the slipstream effects — Bernoulli suction — imply that an outflow is likely to be more common than an inflow, e.g. at the zenith). In high wind conditions the doors will be progressively closed to constrain wind-shake effects to amplitudes that the tip-tilt system can handle. We expect that with dome insulation, the ventilation targets will be met more than 70% of the time.

The ground boundary layer is one adverse effect of the interaction of the UKIRT facility with its environment which we do not expect to be able to address in the Upgrades Programme. Air flowing over the terrain at night cools by contact with the radiatively-cooled surface layer; the flow lines lift when approaching a telescope enclosure (especially a hemispherical one) and thus the boundary layer may rise above the telescope itself. The usual way to avoid such effects is to place the telescope well above the surrounding terrain. Unfortunately the UKIRT dome
Figure 4: The UKIRT dome from the East, showing proposed ventilation apertures

floor is actually at the level of the ground to the East, and elevating the telescope and dome — or lowering the surrounding terrain — by about 10 metres is not an alteration which can be made retrospectively. Evidently, boundary layer seeing will have to be lived with at our facility, although modifications to the North-East dome extension to minimise its likely exacerbating effects on the boundary layer may be contemplated.

5 CONCLUSIONS

A series of quite simple incremental improvements will enhance the performance of the 18-year-old UK Infrared Telescope to make it fully competitive with the medium-sized telescopes of the early 21st century, and for some classes of observations, with the VLTs of that era.

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7 REFERENCES


