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Andy Adamson
John Davies
Ian Robson *Editors*

Thirty Years of Astronomical Discovery with UKIRT

The Scientific Achievement of the United Kingdom InfraRed Telescope

Royal Astronomical Society
Advancing Astronomy and Geophysics

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UKIRT at 30: Foreword

Welcome to this volume of highlights from the celebration of UKIRT's 30th anniversary, held at the Royal Observatory Edinburgh in September 2009. This volume is filled with wonderful accounts of the many technical innovations and newly-blazed trails over the past three decades, together with comprehensive reports of the excellent past, present and potential future science. UKIRT has been a truly remarkable success story.

Despite these many successes, UKIRT's operational funding has been under almost continual threat. At the time of this meeting, the observatory's strategy was to complete the UKIDSS survey programme in 2012 and then to move into planet hunting with a new instrument, the UKIRT Planet Finder. The proposal for this instrument, ably led by Hugh Jones and supported by the UKATC, was, at the time of this meeting, under assessment by STFC. Regrettably, but entirely predictably given the difficult economic constraints facing the organisation, the proposal was not approved. The search for habitable-zone Earth-mass planets around nearby M dwarfs will instead be carried out by other telescopes.

This decision, in combination with other financial pressures, led eventually but inexorably to the biggest single change in UKIRT's long history: in late 2010, UKIRT adopted a "minimalist" operating mode. In this new mode, the observatory's mission is to complete the UKIDSS programme as expeditiously as possible, and UK time is now committed almost entirely to this one programme. There is no more open time, no TAG, and no visiting observers: the telescope is operated remotely from the JAC building in Hilo. It is an enormous credit to the JAC's technical staff that this watershed change was implemented in just 8 months, from the date of approval by the UKIRT Board to the first night of remote operations.

UKIRT has thus evolved from a general-purpose infrared observatory, offering the astronomers of the world a suite of instruments with a range of unique capabilities to one with a single operational instrument and a very narrow, dedicated focus in infrared survey astronomy. This transformation has been enormously successful and UKIRT continues to deliver world-class science data to its users, continuing its long tradition of technical innovation and imaginative solutions.

UKIRT has been a major success story for British astronomy over its 30-year lifetime. On reflection, there are many reasons for this: the excellent infrared site on Mauna Kea; the superb mirror, allowing sub-arcsecond imaging which was not remotely imaginable when the telescope was built; an aggressive development programme leading to a succession of ambitious, world-leading instruments with unique capabilities; and innovative operations, including a suite of software tools for observation execution and data reduction, which make UKIRT second to none for its observers. But the most important reason for UKIRT's success over the years has been the technical excellence and singular dedication of its staff, some of whom are represented in this volume and some of whom are shown in the accompanying photograph. Without them, none of the science described in this volume would have been possible. I am honoured to be the Director of this remarkable observatory.

Hilo, HI, USA — *Professor Gary Davis*
January 2012 — *Director Joint Astronomy Centre*

Some of the staff of the Joint Astronomy Centre (2009)

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Part I
The Development of UKIRT

Chapter 1
The UKIRT Success Story

Richard Ellis

Abstract This is a personal overview of the great success of the UKIRT facility; a tribute to those who designed, built and operated it and helped put UK astronomy at the forefront of world infrared observations. I will illustrate this success with a small selection of science highlights.

Introduction

It's a pleasure to come to Edinburgh to celebrate 30 years of UKIRT operations! All of us feel a close and personal affinity to this remarkable telescope. As with all observatories, it's a combination of excellent support staff and innovative instrumentation that provides the basis for scientific success and it's a privilege to summarize, albeit briefly, the key aspects and discoveries that continue to make UKIRT a world-beating facility.

The UKIRT story really is a remarkable one. For a modest financial investment, the Observatory has played a pivotal role in infrared astronomy for 30 years. It has an unrivalled reputation for technical innovation, cost-effective operations and reliability. It hosts a dedicated staff who willingly take on new responsibilities as required, and work endlessly to achieve the best, often in a hostile environment. And above all, UKIRT has delivered many scientific 'firsts' and built the astronomical careers of many.

In this written version of my Edinburgh talk, I have inevitably had to skip over some of the more amusing aspects of UKIRT's history, but I hope this brief summary conveys the spirit of my talk and the admiration I hold for this 4-m telescope.

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Early History

The engineering concept for an infrared flux collector goes back to the late 1960s and the influential figure of Jim Ring at Imperial College London. The Science Research Council funded the facility to the tune of £2.5M in 1975; in 2009 currency this still only amounts to £10M – the cost of a modest spectrograph for an 8-m telescope! Construction was rapidly completed during 1976–1978 with first light on July 31 1978 and a formal dedication ceremony on October 10 1978.

Others present will remember those early events better than I, but I do have the benefit of a remarkable filing system from my time on SRC/SERC/PPARC committees and can offer some insight into the early discussions.

The case for UKIRT as originally envisaged is succinctly captured at a Royal Astronomical Society meeting held on May 9th 1975 (soon after its funding approval) where Jim Ring states the case for a flux collector and justifies little attention to image quality the requirement for which is only 2 arcsec:

> the consequent saving in cost over an optical telescope is significant..(and) can be put into a larger diameter rather than accurate figuring and support systems (Observatory **163**, p. 95, 1975).

But in February 1977, the minutes of the Astronomy II Committee of the ASR Board of SRC show that the Director of ROE (Vince Reddish) reports:

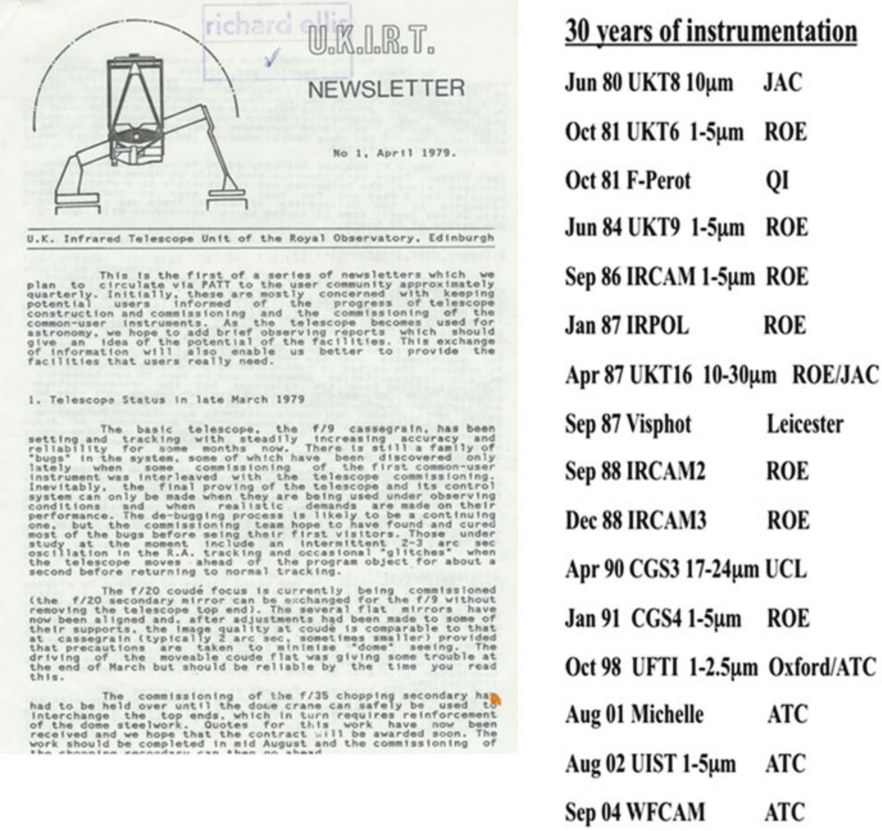
> now that experience has been gained in figuring the blank, it is apparent with comparatively little extra work, 1 arcsec images can be obtained.

The additional cost for this dramatic improvement in image quality was estimated by David S. Brown (Grubb Parsons) at only £12K! It's actually typical of Grubb Parsons and the late Dr Brown that the company should be so cooperative in maximizing the effectiveness of the telescope.

I have also located the first UKIRT Newsletter (Fig. 1.1, left). (Notice the methodical Ellis stamp and prominent 'tick' that indicates I carefully digested its contents in 1979) Peredur Williams was the editor and promises a UKIRT Users' Manual 'soon' (actually it appeared in 1981!). There was no integrating TV, the control computer had a majestic 28K RAM and the Newsletter describes how the observatory earthquake protection system was usefully 'commissioned' with a real Richter 5.1 event. In this historic document one sees a good example of the pioneering, even swashbuckling, spirit that was to become characteristic of UKIRT!

Technical Innovation

Before attempting to review some of UKIRT's science highlights, let's consider the remarkable innovations that have become characteristic of this observatory during the past 30 years.



richard ellis ✓

U.K.I.R.T.

NEWSLETTER

No 1. April 1979.

U.K. Infrared Telescope Unit of the Royal Observatory. Edinburgh

This is the first of a series of newsletters which we plan to circulate via PATT to the user community approximately quarterly. Initially, these are mostly concerned with keeping potential users informed of the progress of telescope construction and commissioning and the commissioning of the common-user instruments. As the telescope becomes used for astronomy, we hope to add brief observing reports which should give an idea of the potential of the facilities. This exchange of information will also enable us better to provide the facilities that users really need.

1. Telescope Status in late March 1979

The basic telescope, the f/9 cassegrain, has been setting and tracking with steadily increasing accuracy and reliability for some months now. There is still a family of "bugs" in the system, some of which have been discovered only lately when some commissioning of the first common-user instrument was interleaved with the telescope commissioning. Inevitably, the final proving of the telescope and its control system can only be made when they are being used under observing conditions and when realistic demands are made on their performance. The de-bugging process is likely to be a continuing one, but the commissioning team hope to have found and cured most of the bugs before seing their first visitors. Those under study at the moment include an intermittent 2-3 arc sec oscillation in the R.A. tracking and occasional "glitches" when the telescope moves ahead of the program object for about a second before returning to normal tracking.

The f/20 coudé focus is currently being commissioned (the f/20 secondary mirror can be exchanged for the f/9 without removing the telescope top end). The several flat mirrors have now been aligned and, after adjustments had been made to some of their supports, the image quality at coudé is comparable to that at cassegrain (typically 2 arc sec, sometimes smaller) provided that precautions are taken to minimise "dome" seeing. The driving of the moveable coude flat was giving some trouble at the end of March but should be reliable by the time you read this.

The commissioning of the f/35 chopping secondary ha[illegible] had to be held over until the dome crane can safely be used to interchange the top ends, which in turn requires reinforcement of the dome steelwork. Quotes for this work have now been received and we hope that the contract will be awarded soon. The work should be completed in mid August and the commissioning of the chopping secondary can then go ahead.

30 years of instrumentation

Jun 80	UKT8	10µm	JAC
Oct 81	UKT6	1-5µm	ROE
Oct 81	F-Perot		QI
Jun 84	UKT9	1-5µm	ROE
Sep 86	IRCAM	1-5µm	ROE
Jan 87	IRPOL		ROE
Apr 87	UKT16	10-30µm	ROE/JAC
Sep 87	Visphot		Leicester
Sep 88	IRCAM2		ROE
Dec 88	IRCAM3		ROE
Apr 90	CGS3	17-24µm	UCL
Jan 91	CGS4	1-5µm	ROE
Oct 98	UFTI	1-2.5µm	Oxford/ATC
Aug 01	Michelle		ATC
Aug 02	UIST	1-5µm	ATC
Sep 04	WFCAM		ATC

Fig. 1.1 (*Left*) UKIRT begins with the first Newsletter. (*Right*) 30 years of innovative instrumentation – a new capability every 18 months!

From the outset the telescope set a new standard with its lightweight thin primary, and later the tip-tilt secondary and cooled primary mirror. However, UKIRT has also been in the vanguard in pioneering new operational concepts. It was amongst the first to routinely offer remote operations (from Edinburgh) and later service observing and flexible scheduling. The current model whereby selected PIs observe on behalf of a group of programs is unique and very popular with the community.

An unchanging telescope is a stagnant facility and UKIRT has also pioneered a continuous set of new instruments and upgrades[1] (Fig. 1.1b). Infrared capabilities

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[1] Soon after I returned to Pasadena from the enjoyable meeting at Edinburgh, I learned of the sudden passing of Tim Hawarden who had been present at the meeting and did so much for the UKIRT upgrades program. Here is not the place for a tribute but this is a sad loss for Edinburgh and the global infrared community.

undreamt of during the 1970s such as integral field unit spectrographs and mosaiced arrays not only first appeared on UKIRT but set a pace and standard in science discovery that other facilities struggled to match.

Ten years after first light, by the time of the 19th UKIRT Newsletter in March 1989 (with Peredur Williams continuing his gallant service as Editor!), UKIRT had the world's first common-user infrared array (c.f. Ian McLean's contribution in this volume), a world-beating infrared spectrograph, CGS2, reaching $K = 14$ (1σ 1s), a control computer with 16 Mb RAM and an image quality of better than 0.9 arcsec FWHM for 90 %. Productivity was an impressive 50 refereed papers per year.

Science Highlights

It's hard to summarize 30 years of frontier science in a few remarks, so what follows is very much a personal selection arranged to span the panoply of instruments and science territories.

As someone who works on distant galaxies, I have to begin by emphasizing that the present dominance of near-infrared studies of the distant universe (now commonplace through NICMOS and WFC3/IR campaigns on Hubble and dedicated survey facilities such as VISTA), truly began at UKIRT. Despite the handicap of single-object photometers, UKIRT pioneered the Hubble diagram of distant radio galaxies and even undertook surveys of nearby galaxies – measured one by one – to construct the first field K-band galaxy luminosity function (Fig. 1.2). Later, with early infrared arrays, came the study of distant clusters of galaxies and their lensed arcs and faint galaxy counts. Quite simply, UKIRT moved into a league of its own. Most recently, the key role of UKIRT in pushing the frontiers was demonstrated in the discovery of the most distant $z = 8.26$ gamma ray burst (Tanvir et al. 2009).

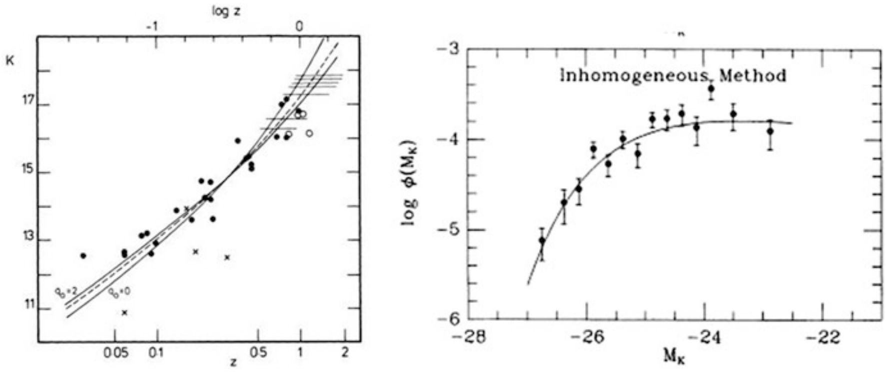

Fig. 1.2 (*Left*) The K-band Hubble diagram of distant radio galaxies from the study by Lilly and Longair (1984); (*right*) the first field galaxy luminosity function at near-infrared wavelengths from the study of Mobasher et al. (1993)

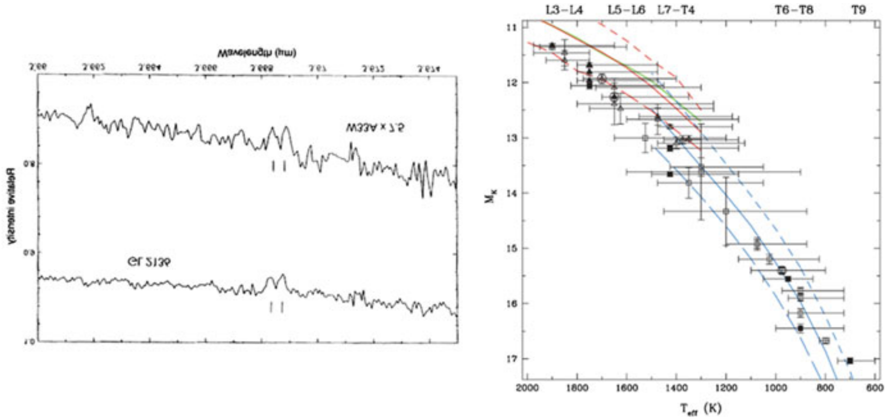

Fig. 1.3 (*Left*) Detection of the ortho-para doublet of $H_3{}^+$ (marked) in the spectrum of two YSOs from the study of Geballe and Oka (1996). (*Right*) Luminosity-effective temperature relation for SDSS-selected L and T-dwarfs from Golimowski et al. (2004)

Cooled grating spectrographs, CGS2 and later CGS4, championed wider territories in astrophysics. Highlights include the detection of the molecular $H_3{}^+$ ortho-para doublet seen in absorption in young stellar objects by Geballe & Oka, a challenging observation that confirms the key role of this molecule in the production of complex molecules and ion-neutral interstellar chemistry, and systematic observations of L and T-dwarfs by Leggett, Geballe, Golimowski and collaborators, which led to new classification methods and tests of model atmospheres in the sub-stellar regime (Fig. 1.3).

For a telescope originally conceived without regard to image quality, I have chosen some examples that demonstrate how UIST and UFTI, instruments designed to match the excellent seeing on Mauna Kea, pushed the frontiers. Willott et al. (2003) used UIST to locate and measure the black hole mass in a $z = 6.41$ QSO; this is a pioneering observation exploiting UKIRT's unique access to the redshifted Mg II emission line. Swinbank et al. (2005) used the integral field unit of UIST to map the resolved dynamics of a $z = 2.385$ sub-millimeter galaxy – consider the angular scale in Fig. 1.4 in the context of Jim Ring's remarks in 1975! Lucas and Roche (2000) exploited UFTI to chart young brown dwarfs and planets in the Trapezium region, thereby constraining the initial mass function down to an unprecedented 20 Jupiter masses.

Finally, to the present day and WFCAM. As others will discuss this remarkable survey capability in some detail, I thought I would steer clear of UKIDSS and just touch on two surveys that have exploited narrow-band imaging with this mosaiced array. HiZELS is an impressive set of surveys that exploits a narrow-band capability to either search for Hα imaging at $z \sim 1$ or, more speculatively, Lyα imaging at very high redshift. In the former case, Sobral et al. (2009) have surveyed the COSMOS

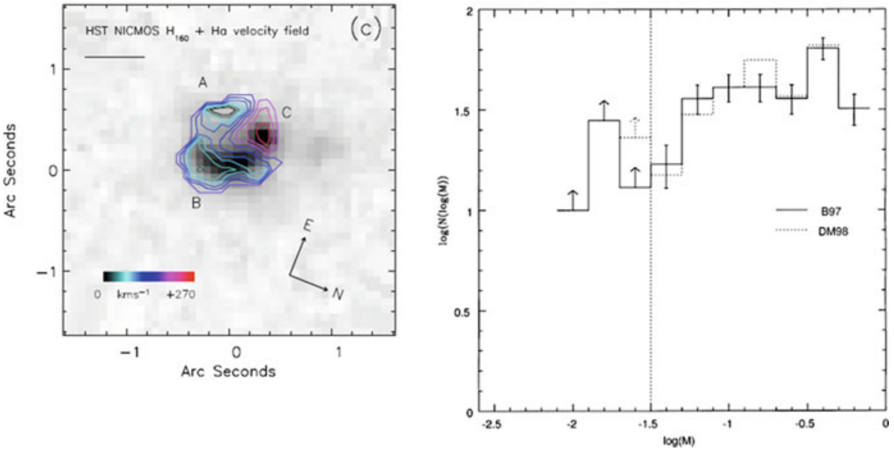

Fig. 1.4 (*Left*) Resolved velocity field in Hα for a z = 2.385 sub-mm galaxy from UIST IFU observations overlaid on a HST NICMOS H-band image demonstrating the importance of galactic outflows in early star-forming systems. Note the remarkable angular resolution (Swinbank et al. 2005). (*Right*) Sub-stellar initial mass function (in solar units) from the Trapezium study of Lucas and Roche (2000)

and UDF fields to undertake a measurement of the star-formation density at z ∼ 1. Together with similar measures at other redshifts, a self-consistent star formation history has been deduced for the first time using the same tracer.

Closer to home, C. Davis and colleagues (Davis et al. 2009) have mapped a phenomenal 8 deg^2 in Orion in the 2.122 μm emission band of molecular hydrogen, locating over 100 objects and associating them with protostellar objects. The level of detail in these maps is truly astonishing (Fig. 1.5).

Studies of the productivity of UKIRT have underlined its global role in astronomy. Trimble et al. (2005) and Trimble and Ceja (2007) examined the output and citation rate of the world's 4-m telescopes and place it alongside CFHT, NTT and WHT – optical telescopes that serve a more diverse community. Chris Benn (unpublished – see http://www.ing.iac.es/~crb/cit/9903_prelim.html) examined the fraction of highly-cited (top 2 %) of world literature over 1999–2003 and reached similar conclusions. UKIRT ranks equal to CFHT, WHT and AAT and outpaces all other dedicated infrared telescopes (e.g. IRTF) by a significant margin.

Summary and Future

So why is UKIRT so successful?

- It is blessed with being on a good site; Mauna Kea offers excellent seeing and a stable thermal environment.
- The joint operations with JCMT via the JAC is remarkably cost-effective.

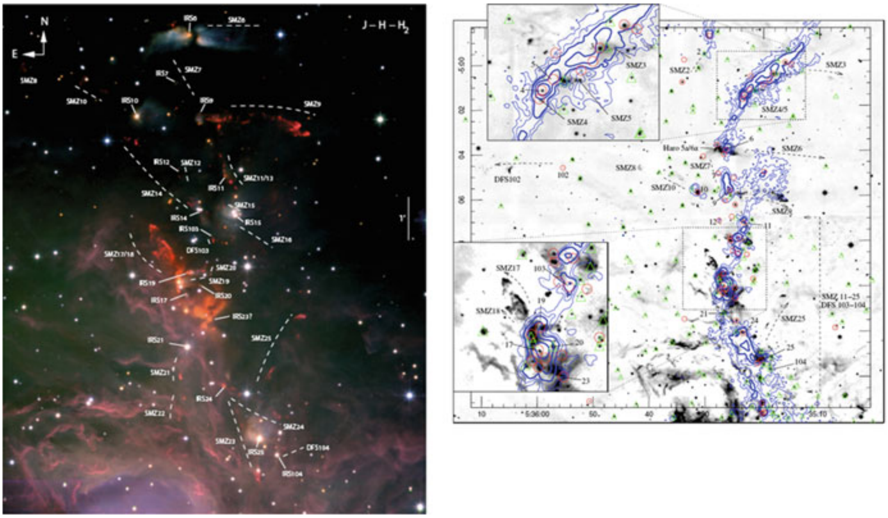

Fig. 1.5 The remarkably detailed mapping of Orion in molecular hydrogen from the study of Davis et al. (2009). (*Left*) Color composite of the region around M43 based on J, K and 2.122 μm imaging; H_2 flows are labeled. (*Right*) 2.122 μm image with protostars marked (with *inset* zooms at twice the scale). Contours refer to 1.2 mm MAMBO data

- It has maintained a flexible suite of front-rank instruments.
- It has championed creative operational models including remote observing and flexible scheduling, noting the importance of training young enthusiastic observers who then become its supporters.
- It has provided powerful online data processing capabilities.
- It has shown again and again that it can reinvent itself, e.g. moving into high resolution imaging (UFTI) and now panoramic surveying (WFCAM/UKIDSS).

The future of UKIRT should therefore be bright! In 2005 I chaired an international review of UKIRT with a charge to make recommendations to PPARC on its "role and international context during 2005–2015 and options for development of the facility". We took this charge very seriously but perhaps as an omen of what has since passed we received no financial guidelines from PPARC. It's hard to see that our carefully-argued case for a bright future for UKIRT had any impact on STFC. As I write this summary of my September 2009 talk, the outcome of the Science Prioritisation Exercise 2010–2015 has just been published by STFC and UKIRT's future in this period looks decidedly unclear.

UKIRT has been a great success not only for UK science but also in promoting the growth of infrared astronomy worldwide. It is one of the best examples of a telescope that has adapted to new technologies, far surpassing the modest goals envisaged in the 1970s. It is sad that STFC should, apparently, not appreciate both the cost-effective operational model that has been a highlight of UKIRT over the past few years as well as the strategic importance of maintaining a UK presence on

Mauna Kea amongst a set of international ground-based observatories that remain, collectively, the most productive scientifically. It will be sad indeed if the UK detaches itself from the Mauna Kea community, particularly given the glorious history blazed by UKIRT and its remarkable staff over the past 30 years.

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Chapter 2
UKIRT – The Project and the Early Years

Terry Lee

Abstract This is a personal overview of the early years of UKIRT, from its inception to the first observing years, showing how many of the decisions taken have turned out to be crucial in giving UKIRT such a high scientific profile. The theme of a common-user facility in terms of the user-experience was novel for the time but set the scene for the next generation of 8 m telescopes many years later. I also pay tribute to the many people who have made UKIRT such a tremendous success.

Introduction

Thirty five years ago I was on a bus in Geneva. I heard a strong baritone voice a few rows behind say "So the UK is going to build an infrared telescope on MK. No one in the UK has done much IR except Aitken and Jones". Well Eric Becklin, who was to become a dear friend, was right, especially if you exclude those Brits who had spent time at Caltech such as Mike Penston – who he was addressing at the time. Nonetheless, many of us had recognized the potential of that part of the electromagnetic spectrum. Indeed, the proposal for a major UK IR facility was first made in 1968. At that time astronomers in the USA were reporting observations using lead sulphide (PbS) detectors (e.g.: stellar photometry by Harold Johnson, a 2 μm sky survey by Leighton and Neugebauer), while for work at longer wavelengths Frank Low was using the gallium doped-germanium bolometer, his invention (sadly, Frank died this summer).

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Jim Ring, Professor at ICST, was interested both in infrared astronomy and telescope design. In particular, he wanted to explore the limits of passive designs for seeing-limited telescopes as the primary diameter increases. [At that time one arcsec was assumed to be the seeing-limit from the ground.] He also sought to challenge the cost-diameter relation for their construction: the cost of building a telescope of traditional design increased as the third power of the primary diameter or faster. By replacing the primary mirror of 6–1 diameter-to-thickness ratio with a thinner one supported by a sufficient number of air-filled pads, the mass of mirror plus cell would be significantly reduced. In turn, the mass of steel and concrete needed to support the optics would be less. Constructing a telescope with this type of design would not pose a risk to observations that do not need seeing-limited images. At the time the argument was that because the internal noise in the PbS detectors was greater than the thermal noise from the sky and telescope for apertures of several arcsec, photometric measurements did not require good image quality.

As a first step the Science and Research Council (SRC) funded a 1.5 m precursor, 'the IR flux collector' that was installed at Izañia on the Island of Tenerife in 1972. This instrument was mainly used by UK and Spanish astronomers, many of us learning how to set up instruments and observe in the infrared for the first time. Researchers who had gained experience in the USA were also able to use it to continue their work. It also indicated that the design concepts for a thin-mirror telescope were sound.

In 1973 Jim Ring and Gordon Carpenter, the senior engineer at ROE, made a proposal for a fully functional, major IR flux collector; either a 3.8 m instrument to be sited alongside the 1.5 m at Izañia or a 3 m instrument on Mauna Kea, a much higher and drier site in Hawaii. In the event the Astronomy Committee led by its chairman, Professor Walter Stibbs, forwarded a proposal for the 3.8 m version on Mauna Kea! This was approved in June 1974. Gordon Carpenter was appointed as Project Manager and the '3.8 m Flux Collector Steering Committee was formed, drawing members from the active infrared groups in the UK. The first task was to study the draft specification and recommend changes, especially in the light of recent developments.

There are significant differences between the design of telescopes used for infrared observations and optical telescopes, the break-point being around 2 μm, longward of which thermal emission from the sky and the telescope dominates the background radiation. For photographic work in the optical stray-light baffles were generally placed around the primary and secondary mirrors and inside the central hole of the primary. Effectively these have a thermal emissivity close to unity. However, for the infrared, any structure in the light path must be minimised. Furthermore, sky emission and gradients must be subtracted from the object and for the single detector instruments of the time, chopping and nodding techniques were used. The subtraction of gradients is more accurate the closer in time that the measurements in the two beams are made. In addition, nodding placed requirements on the dynamic performance of telescope.

Key Elements of the Design

- Lightweight primary supported by 80 pneumatic pistons
- Fast primary ($f/2.5$) to keep tube short
- Clean structure thermally
- Light structure, no central box thermal and cost considerations
- Large diameter gears quick movement
- Position control loop closed in computer
- No control system independent of computer
- Keyboard input supplemented by a few buttons

Specification:

- Primary diameter 3.8 m
- $f/9$ Cassegrain, $f/20$ coudé
- Primary image quality 98 % EED 2.4″
- Short nod time (2s)
- Tracking (5 arcsec per hour)
- Pointing 30 arcsec circle rms
- Dome building to be as small as possible (to contain costs and maximize slit to volume ratio to work against dome seeing)

The principal amendments to the spec as recommended by the steering committee were the following: (1) increase the maximum payload on the instrument rotator from 100 to 200 kg. [At that time a complete photometer might weigh 25 kg and the possibility of mounting multiple instruments and indeed some increase in size was anticipated (though the like of CGS4 was clearly not)]; (ii) a modest increase in the dome size would enable a chopping secondary to be accommodated; (3) the possibility of including an option for improving image quality to 90 % in 1 arcsec should be explored.

The proposed optical and mechanical design was based on such primary mirror blanks as were immediately available – Owens-Illinois Cer-Vit. Where practicable British suppliers and contractors were chosen for building and telescope, and Grubb-Parsons of Newcastle on Tyne for grinding and polishing the optics (having recently done a fine job with the AAT mirrors). The contract contained a provision for continuing to figure the primary mirror beyond the initial specification if testing and evaluation at that stage indicated that it was possible to do so and a price could be agreed. Hadfields of Sheffield was the contractor for the telescope structure and drives. The telescope columns carrying the north and south bearings are tied together, their bases rest on concrete piers via steel thrust-races which allow movement between the piers and telescope structure. Normally horizontal movement is constrained by pins between the steel bases and the piers; these shear to protect the instrument during significant earthquakes. The estimate for the mirror mass was 7 tons as opposed to 15 for a conventional one and the rotating mass was estimated to be 60 tons as opposed to about 250 tons.

A novel feature of the project was to give the tasks of slewing and tracking to a digital computer rather than a set of hard-wired electronics. The user interface was a keyboard and text display, while the RA and Dec axis encoders and sidereal and UT clocks were interfaced via CAMAC, the standard interface for high energy physics at the time. A DEC PDP11 was chosen as the real-time computer running RT11 in 28K words of 16 bit memory. By today's standards this seems very pedestrian, but remember Moore's Law: 30 years worth is a factor of more than a million! Design and programming of the real-time software was done at ICST. A computer was needed to calculate corrections due to atmospheric refraction and uncompensated mechanical movement. Giving it the additional task of closing the position loop saved on the cost of building the digital and analogue circuits and panels. In practice it provided the bonus of an easy upgrade path both to interface and control aspects.

Early Project Developments

The project as originally funded was for the telescope alone, which fell short of what was required for observational astronomy. Clearly there were a number of ways in which the efficiency and effectiveness of the facility could be assured.

1. The addition of a chopping secondary, which experience in the U.S. showed can yield a given photometric observation in a much shorter time than with a focal plane chopper.
2. A detector test and development programme. High purity InSb detectors had become available that were much more sensitive than earlier versions and the standard PbS device of the time. Indeed, developments led to detector noise becoming smaller and smaller through the late 1970s and it had become vital to understand how to get the best out of detectors and to match the optical and cryogenic performances of instruments to suit their needs.
3. The provision of common-user instruments to allow and indeed encourage investigators without infrared equipment or experience to make infrared observations.
4. The setting up of a computer system to control instruments and to log and reduce data in real-time. This enables the astronomer to assess the content and quality of data and to modify the programme accordingly; it also lessens fatigue and the tendency to make mistakes at altitude.
5. The use of intensified TV acquisition and guiding facilities to make target identification easier, to reduce the total duration of an observation (and hence increase efficiency), and to take the guide telescope out of the astrometric loop.
6. The construction of a central Telescope Simulation Facility where investigators can bring their instruments to ensure compatibility with the telescope and test elements of performance (Fig. 2.1).

The content of a possible development programme was discussed at a number of meetings of the Steering Committee leading to a formal proposal by the Royal

Fig. 2.1 Picture of simulation rigs – forerunners of two more generations now at ROE

Observatory Edinburgh to the Science Research Council. During this time I visited several of the labs in the US and the groups in the UK interested in active involvement. In the summer of 1976 a working group met to define details of the first phase of common-user instruments.

The Common-User Instrumentation Plan

- Focal plane choppers for *f*/9 (1 ROE 1 ICST).
- Photometers for *f*/9 Cassegrain: two cryostats using InSb detectors with bandpass filters and CVFs covering 1–5.6 μm.
- Photometers for *f*/35 Cass: two cryostats with bandpass filters and CVFs covering 1–5.6 μm
- Cryostat with bolometer detector and filters covering 3.8–40 μm
- Cryostat with bolometer or doped Si detector with bandpass filters covering 8–40 μm, and a CVF from 8 to 14 μm
- Polarimeter insert (in collaboration with Hatfield Polytechnic)
- Fast photometer
- Visible photometer (UBVRI)
- Cooled grating spectrometer

One of the crucial decisions to be made was the configuration of the instruments at the Cassegrain focus. Infrared detectors must be cooled to their optimum working

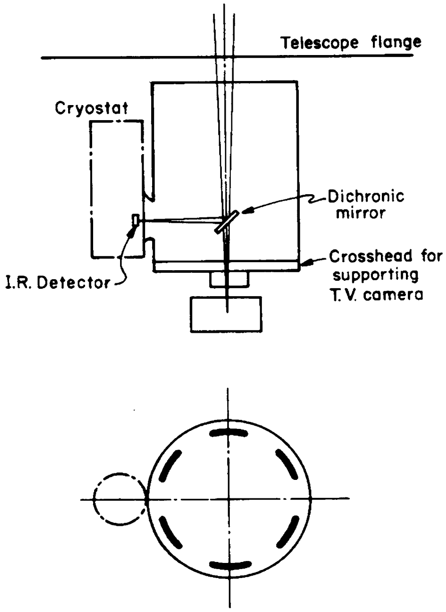

Fig. 2.2 The side-looking configuration

temperatures, which is 77K or lower for near-IR and 4K or lower for longer wavelengths. Cryogenic engineering constraints meant that normal practice was to build the cryostat so that the work surface is the bottom face of a cryogen tank. This configuration is optimal for cryogenic performance and also works well for mounting the detector and optical components with the light beam entering radially, i.e. a bent Cassegrain configuration requiring a tertiary mirror outside the cryostat. This warm mirror is not best suited for thermal infrared work. Some US astronomers were using upward-looking cryostats that were optically efficient (doing away with the reflecting mirror). However, these were more complicated to build, had relatively short hold-times and needed to be demounted from the telescope to fill. The side - looking configuration had the particular advantage that if the tertiary mirror is also a dichroic, the visible light passing through it can be used for acquisition and guiding. This was an important consideration for a new telescope of new design where acquisition, tracking and offsetting properties were not predictable. Furthermore, if this tertiary is mounted on a hollow bearing concentric with the telescope axis then several instruments can be mounted on the telescope at any one time providing backup in the case of problems, or choice. Longer hold-times allow refill operations to become a routine daytime task. So the choice was made. We bought six cryostats from Oxford instruments to a jointly developed design. These featured a long hold-time, flats on the outer casing for mounting motors and windows along with fittings for pumping on the inner vessel (see Fig. 2.2).

InSb detectors were sourced from SBRC or Cincinnati Electronics in the USA. Interference filters were purchased from OCLI Europe in Scotland. We specified

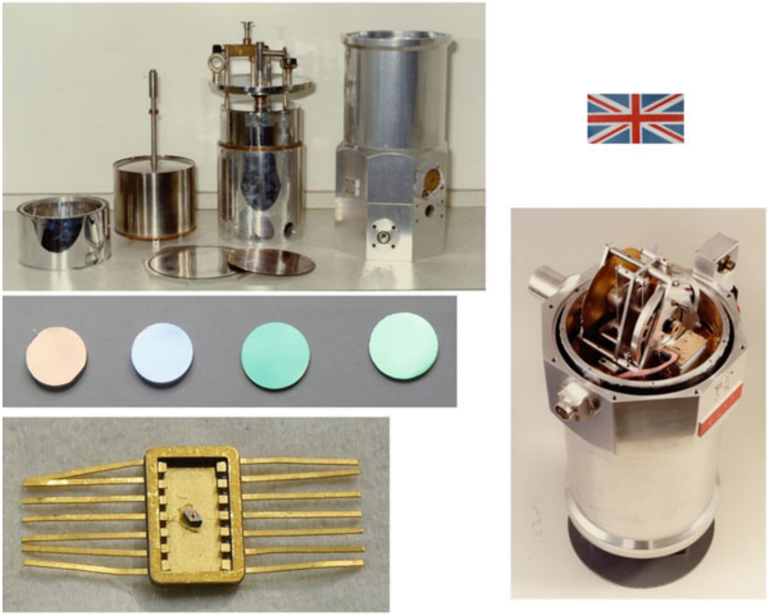

Fig. 2.3 Photometer cryostat with components

filters to match the atmospheric windows (rather than hunting for closest available from surplus catalogs). To limit cost to the project we ordered 50 sets and sold about half to IR groups around the world (Fig. 2.3).

Telescope Realisation

The first landmark in the manufacture of the telescope occurred when David Brown of Grubb Parsons informed us that the specification for the primary figure had been achieved. Furthermore, we were told that it could be improved to a quality of 95 % encircled energy in 1 arcsec for a payment of £20,000. When the proposal was put to the steering committee the decision to accept was made in record time. This subsequently turned out to be a first-class value-for-money decision in the scientific productivity of UKIRT.

The structure and optics were shipped to Hawaii at the end of 1977, and the telescope was assembled in the dome, which had been completed on Mauna Kea early in 1978. Interestingly it was as part of the shipping process that the ‘3.8 m Flux Collector’ became known as UKIRT, analogous to the recently arrived IRTF and CFHT. This gave us an obvious identity and a place on the map locally in Hawaii.

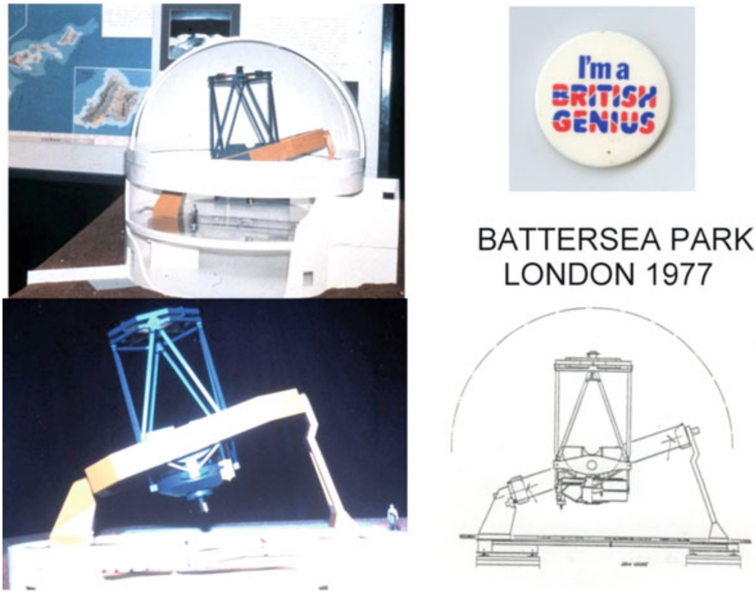

Fig. 2.4 A model demonstrating the design of the telescope was part of the British Genius Exhibition of 1977 in Battersea Park in celebration of the Queen's Silver Jubilee

In 1977 as the project was well underway, two contrasting events happened in close unison: Her Majesty the Queen visited the Silver Jubilee exhibition on May 27th (see Fig. 2.4) and tragically, Gordon Carpenter died on June 1. I was in Sheffield at Hadfields at the time. Following Gordon's death, management of the project was taken on by Colin Humphries. Colin was already part of the project as manager of the optics.

First Light

First light was obtained at 03:23 am on July 31st 1977. Alpha Peg images appeared circular and about 2 arcsec in size. Testing various aspects of the telescope in its $f/9$ configuration continued through 1978. The optical image quality was investigated using a Hartman screen and plate photography, knife-edge tests and examination of out-of-focus images. Two effects were shown to deteriorate the basic image quality much of the time: dome seeing due to warm air in the building, and oscillation in RA (of up to 5 arcsec) due to the nature of the position encoder.

The good news was that the mirrors and supports behaved within specification. Later, in early 1979, when there was a TV camera mounted and differential air temperatures were low, from time to time images appeared to be smaller than 1 arcsec in diameter. Jim Ring's telescope concept was demonstrated. A telescope with excellent image quality had been built for a modest cost.

Other results from these shakedown tests were:

- Pointing within spec (30 arcsec rms).
- Tracking was strictly within spec but the oscillation was not acceptable for observing.
- Nod performance was poor, typically about 5 s for small nods.
- Guide telescope flexed too much with respect to the main structure.
- Crosshead for the autoguider had drives errors.
- Dome drive was marginal even in moderate wind.
- *Dome crane was not safe to lift top end.*

This last was to cause a major delay as strengthening work had to be carried out through the summer of 1979. After strengthening of the dome the dome drive continued to be unsatisfactory and it was some years after the replacement of the track, bogies and drive that reliable automatic dome following of the telescope was achieved.

By the end of 1978, the main testing was completed; mounting of the *f*/35 was rescheduled until after dome work completion. Hadfields were to return to do this and try to improve dynamic performance of the telescope. The telescope became available to the operations team to install wiring and piping through the structure to the Cassegrain area to enable the instruments to be installed. The tasks were then to improve pointing and tracking and to commission the infrared photometers.

Early in January 1979 Dave Beattie prepared and I mounted UKT1 on the telescope. At dinner Eric Becklin said "I hear you guys are going to get first IR, can I come and watch?". We agreed. At the telescope the conversation went something like this:

Eric: "What size aperture do you have"
Dave: "5 arcsec",
Eric: "Do you have a bigger one"
Dave: "Yes"
Eric "Are you going to use it?"
Lee and Beattie in unison: "No"

Back in the control room we set the telescope on the target, centred it on the TV and immediately we had signal. Even Eric was a little impressed. PATT-allocated operation started with the last quarter of 1979. The ICST group took the first slot (Fig. 2.5).

Fig. 2.5 Terry Lee with the first photometer on UKIRT

Dedication

On the 10th October 1979 the Duke of Gloucester opened the facility, now officially called UKIRT, with a ceremony in the dome. Among the dignitaries were Vince Reddish (director ROE), Geoff Allen, (Chairman of SRC), other telescope directors, Harry Atkinson (SRC director of science), University of Hawaii Chancellor, those involved in constructing the facility and many others. Sadly, not Jim Ring who, perhaps wisely, had a fear of flying (Fig. 2.6).

This was followed by an evening dinner in Hilo. Round about 3 am myself, Gareth Wynn-Williams and others finally persuaded a relaxed Harry Atkinson to divulge who was to succeed Vincent Reddish as Director ROE. The answer was of course Malcolm Longair. For me this was an unknown quantity and the changeover was nearly a year away. I had my own Observatory to run and a year's worth of users to serve. Since it was a low-cost telescope we were expected by certain quarters to operate it in proportion cost – but users would expect good service!

It's worth recalling that in those days, long distance communication was a completely different picture from today. There was no internet; written communication was by letter or TELEX (110 b/s). It was not possible to direct dial an international phone call from Hawaii. Summit phones were via a low capacity microwave link able to support voice only. These realities, combined with the time difference between Hawaii and the UK, meant that volume and frequency of communication were not great. We worked rather independently. We were only a dozen or so from the UK at the time and added staff recruited locally.

Fig. 2.6 Vincent Reddish (Astronomer royal for Scotland) and Duke of Gloucester. *Top*: Geoff Allen (Chairman SERC), Min Lee, Des Hickinson (of Hadfields). *Bottom*: Colin Humphries, Terry Lee, Duke of Gloucester

How We Observed

Before we could take on scheduled observing there were issues that had to be addressed. There was no secondary chopper yet, therefore the only choice was to work at *f*/9. For acquisition, no intensified TV camera was yet available, and the combination of the lower sensitivity of the silicon target camera and the restricted field-of-view of the *f*/9 photometer was inadequate for finding guide stars. Guide telescope issues meant that pursuing its use was not fruitful.

The solution was to convert the *f*/35 gold dustbin to *f*/9 use by mounting a focal plane chopper on the end of an arm fixed in one of the six ports. The TV was mounted on the X-Y stage at *f*/9. This gave an offset field of + or-13 arcmin which was very useable. However image motion while tracking was still up to 5 arcsec due to the fine code error of the encoder. This was too big for most projects. I remembered that I had lent a constant voltage source to the telescope project team for factory tests of the telescope drives. It was therefore possible to inject small signals to the RA and Dec amplifiers to drive the telescope in fine motions. After acquisition the computer controlled tracking could be switched off and the analog box switched into the circuit. Inside the analog box was essentially a battery with a few resistors, a couple of potentiometers and a connector for an Atari joystick.