A shared approach to supporting remote observing for multiple observatories

Robert I. Kibrick[a], Gregory D. Wirth[b], Elinor L. Gates[a], Bryant J. Grigsby[a], William T. S. Deich[a], Kyle Lanclos[a], and Steven L. Allen[a]

[a]UCO/Lick Observatory, University of California, Santa Cruz, CA 95064 USA
[b]W. M. Keck Observatory, Kamuela, HI 96743 USA

ABSTRACT

The University of California (UC) began operating the Lick Observatory on Mount Hamilton, California in 1888. Nearly a century later, UC became a founding partner in the establishment of the W. M. Keck Observatory (WMKO) in Hawaii, and it is now a founding partner in the Thirty Meter Telescope (TMT) project. Currently, most UC-affiliated observers conduct the majority of their ground-based observations using either the Keck 10-meter Telescopes on Mauna Kea or one or more of the six Lick telescopes now in operation on Mount Hamilton; some use both the Keck and Lick Telescopes. Within the next decade, these observers should also have the option of observing with the TMT if construction proceeds on schedule.

During the current decade, a growing fraction of the observations on both the Keck and Lick Telescopes have been conducted from remote observing facilities located at the observer's home institution; we anticipate that TMT observers will expect the same. Such facilities are now operational at 8 of the 10 campuses of UC and at the UC-operated Lawrence Berkeley National Laboratory (LBNL); similar facilities are also operational at several other Keck-affiliated institutions. All of the UC-operated remote observing facilities are currently dual-use, supporting remote observations with either the Keck or Lick Telescopes.

We report on our first three years of operating such dual-use facilities and describe the similarities and differences between the Keck and Lick remote observing procedures. We also examine scheduling issues and explore the possibility of extending these facilities to support TMT observations.

Keywords: remote observing, observation scheduling

1. INTRODUCTION

Observatories (like Lick and Keck) that allocate most of their observing time to classically-scheduled observations typically need to provide some level of observer support facilities, such as control rooms, daytime sleeping facilities, and either dining facilities or food preparation areas. When planning such facilities, several important factors need to be considered, as illustrated in Table 1. With the advent of remote observing conducted from external sites, such planning becomes more challenging; as the fraction of external remote observations increases, the demand for support facilities at the observatory decreases while demand at external sites increases. In planning for the next generation of such observatories, it is useful to examine the impact of providing external remote observing for both Keck and Lick Observatories.

Table 1. Factors that affect planning for observer support facilities, shown as a tabular diagram of sets, related vertically

<table>
<tr><td>Factor</td><td colspan="5">Observing Modes</td></tr>
<tr><td>Scheduling Type</td><td colspan="3">Classical Scheduling</td><td colspan="2">Queue Scheduling</td></tr>
<tr><td>Who conducts observations</td><td colspan="2">Regular Observers</td><td colspan="2">Service Observer</td><td>Automaton</td></tr>
<tr><td>Where observations are conducted</td><td>At home institution</td><td colspan="3">“At the observatory”</td><td>Cyberspace</td></tr>
<tr><td>Where observers sleep</td><td>At home</td><td>In dorm</td><td colspan="2">Either</td><td>N/A</td></tr>
</table>

Further author information- (Send correspondence to R.K.)
R.K.: Email: kibrick@ucolick.org; www.ucolick.org/~kibrick; Telephone: 831-459-2262; G.W.: Email: wirth@keck.hawaii.edu; www2.keck.hawaii.edu/realpublic/inst/people/wirth/; Telephone: 808-881-3866

2. OBSERVING "AT THE OBSERVATORY"

Conducting observations "at the observatory" has a different meaning depending on whether you are observing at Keck or at Lick. At Keck, it means conducting observations from control rooms located at the WMKO Headquarters in Waimea (32 km away from the telescopes on Mauna Kea), while at Lick it means observing from control rooms located adjacent to telescopes on Mount Hamilton.

2.1 Observing at Keck Observatory

Since 1996, most observations with the Keck telescopes have been carried out from one of the two remote operations rooms located at WMKO Headquarters in Waimea; as of 2008, observing from the Keck control rooms on the Mauna Kea summit is no longer supported. The primary motivation for this was to move observers off of the oxygen-starved summit and enable them to observe with greater safety and efficiency from a nearby facility located at a lower altitude.[1] The Keck I remote operations room in Waimea became operational in 1996, and the corresponding room for Keck II (see Fig. 1) came online the following year. The WMKO Headquarters also provides visiting scientist quarters (VSQ) where users of the remote operations rooms are provided a dark and quiet location to sleep during the daytime. Observers can prepare meals in a well-equipped kitchen in the VSQ or dine at local restaurants, several of which are within walking distance to the headquarters building.

The observer is supported by an observing assistant (OA) who operates the telescope, and a support astronomer (SA) who assists the observer in setting up and operating the instrument. During the first part of the night, an SA is present in the remote operations room and during the latter part an on-call SA can be reached by telephone at home. The OA is usually located at the summit, but in some cases will operate the telescope from the same control room in Waimea from which the observer is running the instrument. A video-conferencing system links each remote operations room in Waimea with its corresponding telescope control room at the summit.

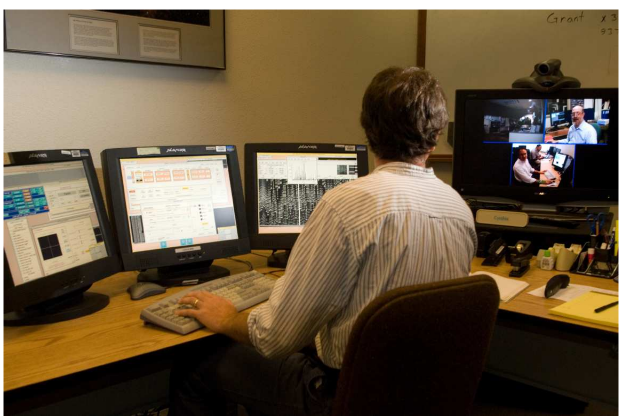

Figure 1. Remote operations room at Keck HQ in Waimea

Figure 2. Shane 3-m Telescope control room at Lick

2.2 Observing at Lick Observatory

Most observations with the Lick Telescopes are still carried out from nearby control rooms located on the summit of Mt. Hamilton. Dormitories are also located nearby to provide observers a dark and quiet location to sleep during the daytime. Small food preparation areas (including small refrigerators and microwave ovens) are now provided in many of these dorm rooms; observers can use more complete kitchen facilities in the recently remodeled portion of the Shane 3-m Dome or in the former dining hall, which closed down at the end of 2007.

While on-site observers can utilize five of the Lick telescopes, we will focus here on the two that currently have the highest usage: the Shane 3-m and Lick 1-m Telescopes. Observers at the Shane 3-m Telescope operate from a control room located just off the dome floor (See Fig. 2). They are supported by a telescope technician (TT), who operates the telescope, and a support astronomer (SA), who assists the observer in setting up and operating the instrument and who remains on-call at home (on Mt. Hamilton) via telephone at night. Observers at the Nickel 1-m Telescope operate from a nearby control room and are responsible for operating both the telescope and its attached instrument. If they need assistance, they can telephone the TT at the Shane Telescope or the on-call SA.

3. OBSERVING FROM THE OBSERVER'S HOME INSTITUTION

3.1 Keck Telescopes

Efforts to enable Keck remote observing from sites in California were undertaken by researchers at the University of California, Santa Cruz (UCSC)[2] and the California Institute of Technology (CIT).[3] A key motivation for those efforts was to reduce the travel time and costs associated with short-duration observing runs.[4] The remote observing facility at UCSC became fully operational in 2001, and served as the model for similar facilities that came online at other UC campuses, at CIT, and at Swinburne University during the following nine years (see Table 2).

Table 2. WMKO remote observing sites (UC-affiliated sites listed in bold)

Number	Name	Rooms	Resolution	ISDN backup[5]	Location	First use
1	WMKO HQ	2	1280 × 1024	no	Waimea, Hawaii	1996
2	**UCSC**	1	1920 × 1200	yes	Santa Cruz, California	2001
3	**UCSD**	1	1280 × 1024	yes	San Diego, California	2003
4	CIT	2	1280 × 1024	yes	Pasadena, California	2004
5	**LBNL**	1	1920 × 1200	yes	Berkeley, California	2005
6	**UCLA**	1	1600 × 1200	yes	Los Angeles, California	2006
7	**UCSB**	1	1600 × 1200	no	Santa Barbara, California	2007
8	**UCB**	2	1920 × 1200	yes	Berkeley, California	2007
9	**UCR**	1	1600 × 1200	no	Riverside, California	2008
10	**UCD**	1	1600 × 1200	no	Davis, California	2008
11	**UCI**	1	1600 × 1200	no	Irvine, California	2008
12	Swinburne	1	1920 × 1200	no	Melbourne, Australia	2010
13	Yale	1	TBD	no	New Haven, Connecticut	late 2010

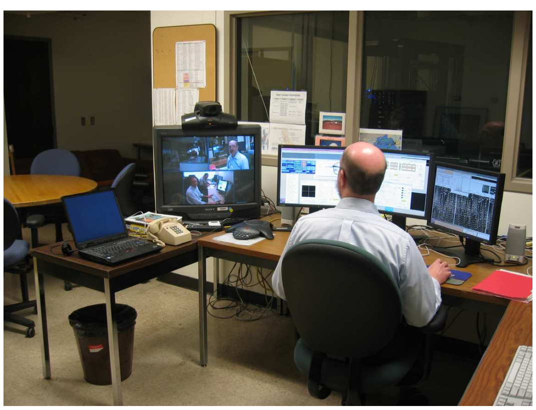

Figure 3. Remote observing room at UCSC

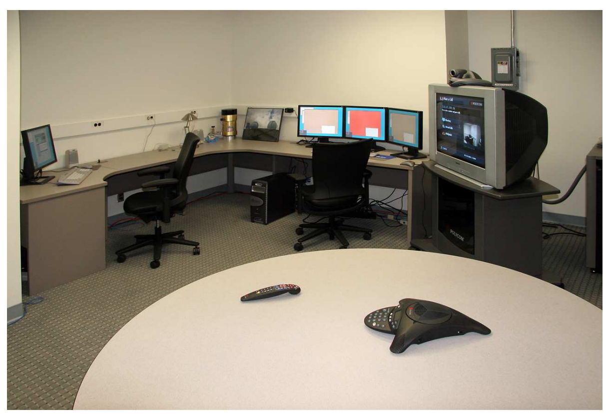

Figure 4. Remote observing room at UCLA

The Keck remote observing facilities in California (e.g., see Figs. 3 and 4) are primarily targeted towards observers who live within commuting distance of one of those facilities;[4,6] no dormitories for observers are provided at these facilities. They are not intended to duplicate the Waimea facility nor to operate independently of it. Rather, each is an extension of the facility in Waimea. That facility and those on the mainland are intended to operate in collaboration, sharing resources where practical. We rely on the existing instrument support staff in Waimea and provide video-conferencing and shared software environments so that they can most effectively support the observers at the mainland sites.

3.2 Lick Telescopes

The success of the Keck remote observing program served as a catalyst for developing a similar capability for the Lick Telescopes in 2007.[7] Since UC-affiliated observers can observe at Lick or Keck, it made sense to utilize the existing Keck remote observing facilities at the UC sites to support Lick remote observing.

Although the instrument and telescope control user interfaces at the two observatories are quite different, both the Keck and Lick remote observing software environments utilize the same type of shared VNC[8] desktops and window managers, thus providing users with a very similar overall look and feel; observers who have previously used one remote observing environment have an easy time learning to use the other. Another similarity is that the Lick program relies on support astronomers located at the observatory site to provide support to the remote observers via the video-conferencing system.

If a conflict arises between between a Keck observer and a Lick observer wanting to use a given remote observing facility on the same night, the Keck observer has priority, for two reasons: the capital costs of setting up these facilities were paid by a grant made explicitly to support the Keck remote observing program, and travel between UC campuses and Waimea is typically more expensive and difficult to book on short notice than travel between those campuses and Mt. Hamilton. As a result, Lick observers who have signed up to use a remote observing facility are occasionally “bumped” by a Keck observer who subsequently requests use of the facility.

4. OPERATIONAL POLICIES AND PROCEDURES

Regardless of the location from which they are working, Keck observers are prohibited from remotely operating the instrument until WMKO staff at the summit have finished configuring it for that night’s observing and have officially released it for use. The current release status for the instrument on each of the two telescopes is posted on WMKO’s Summit Instrument Activities Schedule (SIAS) web page[*] which is accessible to the remote observers.

Lick observers are similarly prohibited from remotely operating the instrument until Lick staff at Mt. Hamilton have released it for use. In the case of the Nickel 1-m, observers are also prohibited from operating the telescope and dome until they have been released. Lick uses a two-step release mechanism that is enforced by a separate software application. Once summit staff have completed telescope and instrument configuration activities, they conditionally release the instrument (and telescope) to the observer. However, that release does not become effective until the observer completes a form providing their name and contact information.

5. MONITORING

Both observatories provide routine monitoring of the network connectivity between the respective telescopes and the various remote observing sites. At Keck, a `mainland_status` script is invoked on a host in Waimea each morning via the Unix *cron* facility. That script uses the Unix `ping` utility to verify that all of the relevant ISDN routers[5] and remote observing workstations at each of the mainland remote observing sites are reachable from Waimea via the network. If any are not, the script sends an email message to the Keck remote observing coordinator[6] and to the manager at the relevant site to alert them of a potential problem. Since some remote observing hosts often go unused for many days at a time, such automated checking helps to provide timely detection of problems that might otherwise go unnoticed until a remote observing session is just about to commence. In addition, Keck employs a PC-based product, SolarWinds, to continuously monitor connectivity, latency, and packet loss to all external remote observing workstations and routers.

At Lick, an existing Nagios[†] monitoring system is leveraged to continuously check on the network availability of remote observing sites. Both latency and packet loss are monitored for each remote observing workstation, and if present, dedicated remote observing ISDN routers are checked as well. If either the latency or packet loss crosses a warning threshold, an email is issued to notify system administrators of the degraded performance; if a critical threshold is crossed, as might occur if a machine was removed from the network, a different, more sternly worded email is issued. In the event of an ongoing problem, emails will continue to be sent on regular intervals until the problem is remedied. Beyond basic notification of service problems, the results of the continuous monitoring can be helpful in quantifying the impact of certain network-based activities on the performance of remote observing. This is especially important given the extremely limited Internet bandwidth currently available at Mt. Hamilton.[7]

[*] `http://www2.keck.hawaii.edu/realpublic/inst/sias.html`

[†] `http://www.nagios.org`

6. USAGE METRICS AND STATISTICS

6.1 Keck Observatory

When the mainland remote observing facilities were first conceived, two distinct modes of operation were envisioned and subsequently articulated in WMKO's formal policy‡:

1. **Remote eavesdropping mode** (permitted from all external sites)
   - At least one member of the observing team observes from Waimea, while the other members of the team observe from the mainland.
   - Observer(s) in Waimea have primary responsibility for instrument operation, but observers on the mainland are able to operate the instrument if desired.
2. **Mainland-only mode** (permitted only from external sites with ISDN backup communications path; see Table 2)
   - All members of the observing team observe from California site(s).
   - California observer(s) have sole responsibility for instrument operation.

With the addition of Melbourne, Australia-based Swinburne University in 2010, the notion of "mainland" sites or California sites has been replaced by "external" sites; i.e., sites external to the WMKO facilities in Hawaii.

In reviewing the use of the external remote observing facilities over the last 4.5 years (see Fig. 5§), several trends become apparent. First, the majority of observing teams that have utilized the external facilities have employed the first mode of operation. While the mainland-only mode has been used from six of the eleven external sites (LBNL, UCSC, UCSD, UCLA, UCB, and CIT), before 2007 such usage accounted for less than 10% of mainland remote observing activity. By the end of 2009, such usage had grown to about 50% overall, as is now the dominant mode at both UCB and UCSD (see Fig. 6).

Second, as expected, the number of nights per month that involve WMKO remote observing from the external sites has grown significantly as more external sites have come online. For example, for 2006, remote observing from those sites was conducted an average of 9.6 nights per month, while for 2007 this figure rose to 12.6; the first six months of 2008 averaged 19.7 nights per month, and the last six months of 2009 averaged 23.8. In May 2010, 28 of the 31 nights in that month involved remote observations being conducted on one or both of the Keck Telescopes from one or more external sites.¶.

Third, an increasing fraction of those nights involved operations conducted from two (or more) different external sites on the same night. Such operations have come about in several different ways. Since there are two Keck Telescopes, two distinct observing programs can take place each night, and each such program could involve observer(s) located at a distinct external site. In addition, for a given instrument on a given telescope, some nights are scheduled as "split nights", where the observing time is split between two (or more) different programs, each with their own observing team; in such cases, each of the two remote sites would operate the instrument for only a portion of the night. Alternatively, a single observing program involving only one instrument and telescope may involve a multi-institution observing team in which team members participate simultaneously from more than one external site; the number and diversity of such programs has increased significantly during the past two years. A recent example involved an observing program in which the observing team was split between the remote observing facilities at 3 external sites (CIT, UCLA, and UCSD), all of which were linked together with each other and with Waimea via the shared VNC desktops[8] and video-conferencing equipment.

When the Keck mainland remote observing program was first initiated, we assumed that it would be used primarily for short-duration (e.g., half-night or one-night) runs because the external sites provide no daytime sleeping facilities and that observers with longer-duration runs would continue to observe from Waimea where such facilities are available. While many still do, a growing number of longer duration runs are now being conducted from the external sites by observing teams in which different team members work different shifts.

‡`http://www2.keck.hawaii.edu/inst/mainland_observing/policy.html`

§The number of "nights" displayed along the Y-axis is computed as the sum of *telescope-night-fractions* summed across both Keck Telescopes and across the number of nights in the given semester. The *telescope-night-fraction* value for a given night on a given telescope represents the fraction of that night (e.g., 0, 0.5, or 1.0) on which the observing program for that telescope included participation from observers working from at least one of the eleven external remote observing sites.

¶Month to month fluctuations reflect a variety of factors, such as telescope time assigned to observers affiliated with institutions lacking their own remote observing facility or nights allocated to interferometry, segment phasing, or telescope engineering.

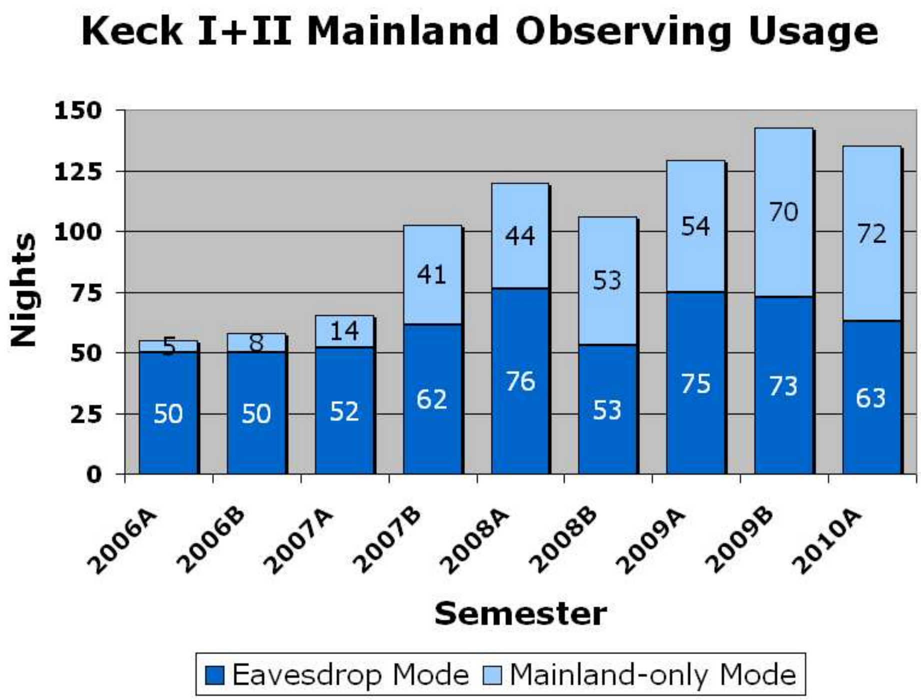

Figure 5. Usage of the WMKO mainland observing system for each (6-month) semester between February 2006 and August 2010. Bottom part of histogram (dark blue) represents "eavesdropping" mode usage and top part (light blue) represents "mainland-only" mode operation. Since early 2007, system usage has been steadily growing, with mainland-only mode becoming increasingly popular. Actual usage during Semester 2010A (which runs through the end of July 2010) will likely be higher than shown here, because this manuscript was submitted at the end of May 2010 and mainland observing requests are often not submitted until a few weeks prior to the actual observing date.

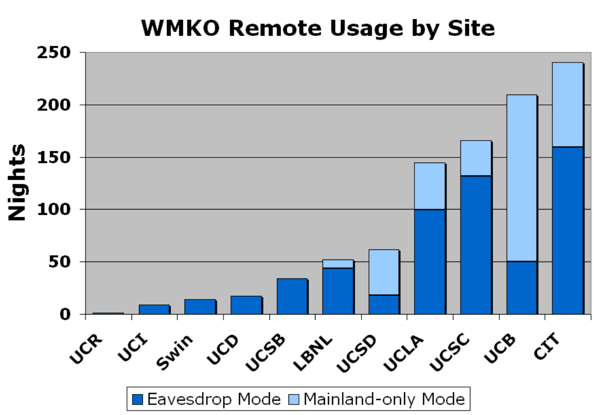

Figure 6. Usage of the mainland observing system by site since February 2006.

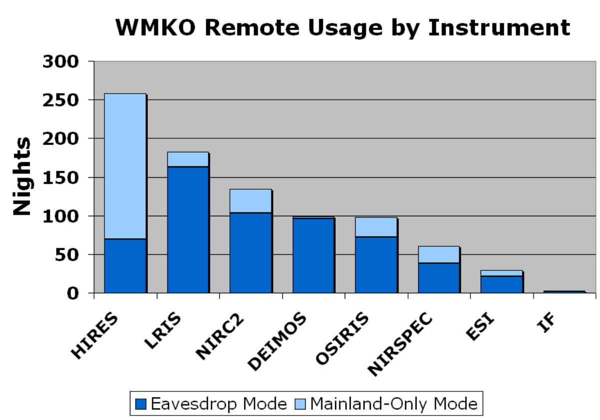

Figure 7. Usage of the mainland observing system by instrument since February 2006.

6.2 Lick Observatory

While Lick Observatory supports both remote eavesdropping and "mainland-only" (i.e., external-only) observing modes, both modes are permitted from all of the UC-affiliated external sites. Overall, the second mode dominates, and accounts for nearly 90% of remote observing activity on both the Nickel 1-m and Shane 3-m Telescopes; see Figs. 8 and 9.

Measured over the last 3.5 years, remote observing with the Nickel 1-m Telescope accounted for 60.9% of Lick remote observing activity while the Shane 3-m Telescope accounted for the remaining 39.1%. However, during the past year, remote usage of the Shane 3-m has drawn even with that of the Nickel 1-m.

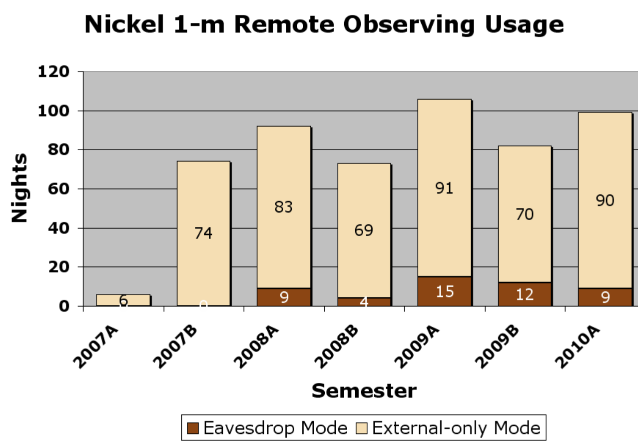

Figure 8. Remote usage of Lick Observatory's Nickel 1-m Telescope for each (6-month) semester from January 2007 through June 2010

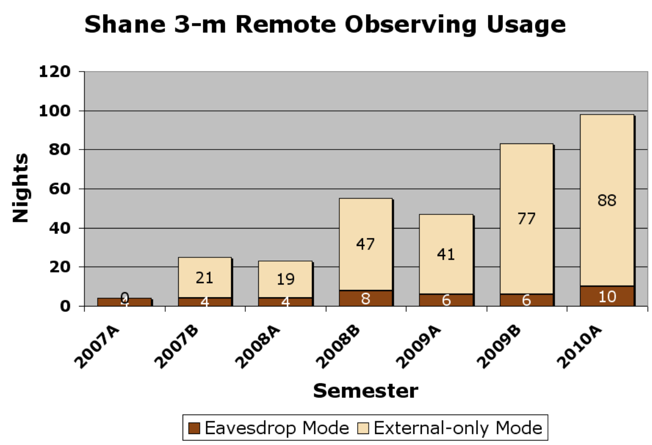

Figure 9. Remote usage of Lick Observatory's Shane 3-m Telescope for each (6-month) semester from January 2007 through June 2010

Since January 2007, over 60% of Lick remote observing activity has been carried out from the UCB campus (see Fig. 10), which is the only UC campus so far to have assembled two remote observing rooms; UCB is also the UC campus with the highest level of Keck remote observing activity (see Fig. 6). Four campuses (UCB, UCSD, UCSC, and UCLA) accounted for nearly 95% of the Lick remote observing activity; these same four also had the highest level of Keck remote observing activity of any of the UC campuses. However, the rankings of these four UC campuses in terms of their respective number of nights of Keck and Lick remote usage are not the same. UCSD shows the largest difference, ranking fourth in terms of its remote usage of Keck Telescopes but ranking second in remote usage of Lick Telescopes. In addition, some campuses (e.g., UCSC and UCSB) had a much higher fraction of eavesdrop-mode usage.

So far, two instruments (one at each telescope) have dominated the remote usage of Lick Telescopes: the Direct Imaging Camera at the Nickel 1-m and the Kast Double Spectrograph at the Shane 3-m. Together, they accounted for over 85% of the remote usage of Lick telescopes to date (see Fig. 11).

The number of nights per semester that involve remote usage of the Nickel 1-m and/or the Shane 3-m Telescopes at Lick Observatory has grown steadily over the last 3.5 years, from 10 nights during the first semester of 2007 to 197 nights in the second semester of 2010 (see Figs. 8 and 9). Further growth is anticipated once the upgrade of the Hamilton Spectrograph control system is completed in late 2010, enabling more efficient remote operation of that instrument.

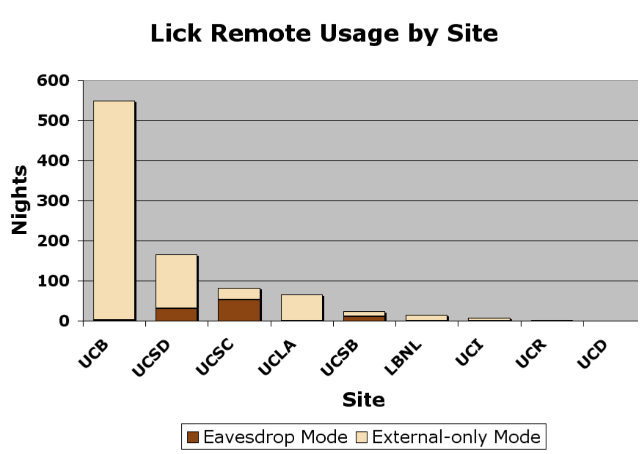

Figure 10. Remote usage of Lick Telescopes for each remote observing site from January 2007 through July 2010.

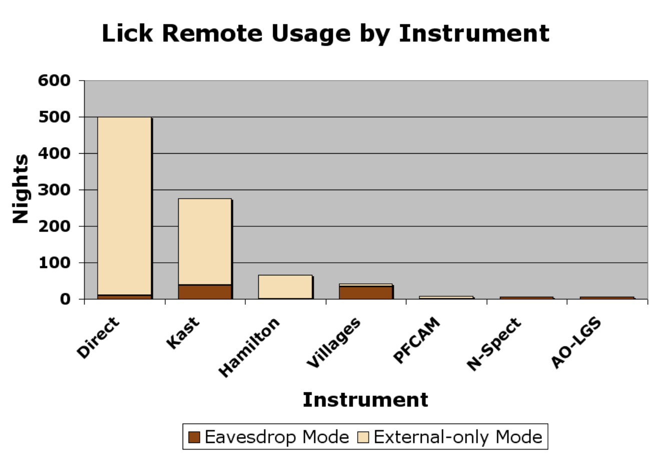

Figure 11. Remote usage of Lick Telescopes for each instrument from January 2007 through July 2010.

7. SCHEDULING CONFLICTS

When observers conduct their observations “at the observatory”, there are usually no conflicts in scheduling the use of control rooms because each telescope has it own dedicated control room. But when observers operate from a remote observing facility at their home institution, the potential for scheduling conflicts exists whenever the number of telescopes that can be operated remotely from a given external site exceeds the number of remote observing rooms available at that site. As the difference between these two numbers increases, so does the likelihood of such scheduling conflicts.

The extent to which such scheduling conflicts arise at any given external site depends on a wide variety of factors, including the number of observers at that site, the fraction of those observers who chose to conduct their observations remotely from that site, which telescopes and instruments they most frequently utilize to conduct their observing programs, and whether the objects each plans to observe are visible in the night sky at similar times of the year. In addition, these factors will likely change over time. As a result, it is difficult to accurately predict the extent to which such conflicts will arise in the future. In practice, such scheduling conflicts in the use of the existing Keck/Lick external remote observing facilities have not been a significant problem for most sites; when a conflict does occur, it is typically at one of the sites with the heaviest Keck and Lick remote observing activity, such as UCB.

Such scheduling conflicts first became apparent with respect to Keck remote observations conducted from CIT. While UC and CIT each receive equal shares of Keck observing time, the UC time is split between a much larger number of observers who are distributed between eight different UC campuses, while the smaller number of CIT observers are all located at the CIT campus in Pasadena. As a result, on any given night, there is a significantly higher likelihood that observers allocated time on Keck I and those allocated time on Keck II will both be affiliated with CIT; if both were to chose to observe remotely from the CIT campus, two remote observing rooms would be needed. When Keck remote observing first commenced at CIT in 2004, only one such room was available, and such scheduling conflicts sometimes occurred. However, in 2009, the CIT astronomy department moved to a new building which was equipped with two Keck remote observing rooms, thereby eliminating such conflicts.

Because the UC-affiliated remote observing sites can support either Keck or Lick remote observing, there is an even greater potential for such scheduling conflicts. Currently, there are two Keck Telescopes and two Lick Telescopes (the Nickel 1-m and Shane 3-m) that can be used remotely. In the very unlikely event that on a given night the observers assigned time on the Keck I, Keck II, Shane, and Nickel Telescopes were all located at the same UC campus and all wanted to observe remotely from that site, four remote observing rooms would be needed at that location; with the exception of UCB, all UC-affiliated sites currently have only one such room.

Although such a convergence has not occurred to date, there have been several instances at UC-affiliated sites where on a given night the observers assigned time on two or more of these four telescopes have all been located at the same campus and all wanted to operate remotely from that site. In such situations, it may not always be possible to accommodate all such requests for remote observing at a given site. Present scheduling policy for the use of UC-operated remote observing facilities dictates that Keck observers have priority over Lick observers, and Shane 3-m observers have priority over Nickel 1-m observers.

The highest likelihood of such scheduling conflicts is at UCB, which is the UC-campus with the highest level of both Keck and Lick remote observing activity (see Figs. 6 and 10). In the worst cases to date, UCB observers were assigned time on three of these four telescopes for the same night and all three wanted to operate remotely UCB. Since UCB currently has only two such rooms, one of the three observers had to make other arrangements. In such cases, since it is typically a Lick observer that gets “bumped,” such observers have the option of canceling their run, or observing either on Mt. Hamilton or remotely from LBNL, which is located close to the UCB campus; however, due to LBNL security restrictions, this second option is currently available only to observers who are U.S. citizens.

When such scheduling conflicts have arisen at other UC-affiliated sites, they have sometimes been resolved by moving the “bumped” observer to a nearby site that is not otherwise scheduled for use on the night in question. Such flexibility is made possible by the collegial relationship that currently exists between the various UC-affiliated remote observing sites. For example, depending on traffic, several of the UC campuses in Southern California (UCSD, UCR, UCI, UCLA, and UCSB) are within a 3 hour drive of each other; the same is true for the Northern California campuses (UCSC, UCB, and UCD). While such driving times are non-negligible, they are still much shorter and the trips less costly than travel to Hawaii, and, for the Southern California campuses, they are still much shorter and the trips less costly than the travel to Mt. Hamilton.

As more telescopes at Mt. Hamilton become remotely operable (e.g., the Coudé Auxiliary 0.6-m Telescope is being modified to enable remote operation by late 2010 or early 2011) and as more observing programs involve observing teams operating collaboratively and simultaneously from multiple remote sites, the likelihood of such scheduling conflicts will increase and require greater efforts on the part of remote observing coordinators and site managers to resolve. Greater automation of the scheduling process will help to reduce this load, and is being actively considered.

An alternative approach that has been proposed for addressing this scheduling conflict problem is to make Keck and Lick remote observing available directly from the workstations that most observers have in their offices; this approach has been implemented successfully by other observatories, such as the NASA Infrared Telescope Facility (IRTF)[‖] on Mauna Kea. While this approach may work well for operating simple instruments (e.g., photometers) whose user interfaces and displays don't require lots of screen real estate, this model becomes problematic when operating more complex instruments that require more screen real estate than is typically found on a user's workstation, such as the existing instruments in operation at Keck and Lick. While video-conferencing can be provided via the user's workstation using inexpensive webcams, these typically don't provide the same capabilities (e.g., remote control of camera pan/zoom, high quality video and audio echo cancellation, multi-conferencing capability, etc.) as provided by the dedicated video-conferencing systems used in our existing Keck/Lick remote observing rooms.

In addition, while the remotely-observe-from-anywhere model may address the scheduling conflict problem, it raises several others. First, there is no way to ensure that an individual user's workstation is running a current version of its operating system and/or web browser (or a even web browser that is compatible with the remote observing applications) and that critical security patches have been applied. Second, an observer may have configured his or her workstation to have non-standard keyboard or mouse button mappings[**] or unusual settings of browser and/or window manager properties, and these may cause subtle operational problems that are difficult for the support astronomers at Keck or Lick to diagnose, since they have no way to reproduce the remote observer's local operating environment. Third, most observers' private workstations have neither the level of UPS backup power that is typically provided to the equipment in our Keck/Lick external remote observing facilities, nor access to a backup, ISDN-based network path as provided at many of those facilities (see column 5 of Table 2). Finally, if remote observers can connect from arbitrary sites around the world, it is much more difficult to provide the level of routine connectivity monitoring (see Section 5) as we currently provide to our existing Keck/Lick remote observing facilities.

8. OTHER CONSIDERATIONS

8.1 Standardization between sites

A key factor in the reliability and maintainability of the Lick/Keck remote observing facilities has been the use of relatively standardized hardware and software at the various sites; the Keck remote observing facilities in Waimea served as the basic model which was then replicated at the various external sites. That model included the use of dedicated H.323-based video-conferencing systems manufactured by Polycom and multi-headed Sun SPARC-architecture workstations running Solaris and employing frame buffers and X servers capable of providing simultaneous support for both 8-bit and 24-bit X visuals, with separate X servers assigned to each monitor.[8]

Unfortunately, with the demise of the Sun SPARC workstation line and the purchase of Sun Microsystems by Oracle Inc., this component of the model is no longer available. Accordingly, both the Keck and Lick remote observing software that runs at the external sites has been ported to run under generic Intel-based systems running Linux and utilizing frame buffers and X servers that lack the capability of simultaneously supporting 8-bit and 24-bit X visuals; this necessary capability was instead provided by new features present in Version 4 of RealVNC[††]. As new Keck/Lick remote observing sites come online, they will employ this Linux-based version of the software; the facility at Swinburne University represents the first site employing this version.

[‖] http://irtfweb.ifa.hawaii.edu/observing/remote_obs/

[**] Such non-standard key mappings can sometimes cause vulnerable software to go awry in unpredictable ways that are difficult to troubleshoot, resulting in a significant loss of observing time. An unfortunate example of such a loss that was ultimately found to have been triggered by unexpected key mappings is described at the start of an article in the August 27, 2006 edition of Time Magazine, *How the Stars Were Born*, available at http://www.time.com/time/magazine/article/0,9171,1376229,00.html

[††] http://www.realvnc.com

The first few remote observing sites used monitors with 1280×1024 (horizontal x vertical) pixel resolution, so the shared VNC desktops used for remote observing were sized accordingly. As newer sites came online, they typically had higher resolution monitors, either 1600×1200 or 1920×1200 pixels (see column 4 of Table 2), and many of the original sites have upgraded their monitors to these higher resolutions. Since 1280×1024 is currently the least common denominator between the various sites, that is still that default size of VNC desktops currently used for Keck remote observing. While this ensures that each VNC desktop can be fully displayed (without scroll bars or re-sampling, thus ensuring that all connected sites see the same VNC desktop rendered in the same way) at any of the Keck remote observing sites, it also means that screen real estate is not used efficiently at many of them. However, until WMKO upgrades the resolution of the monitors in its two remote operations rooms in Waimea, this small-sized VNC desktop will likely remain the default for Keck remote observing.

The situation for Lick remote observing is somewhat different, because the monitors in use at the control rooms on Mt. Hamilton and at most of the UC-operated remote observing facilities already support these higher resolutions. Accordingly, the VNC servers that run on the computers at Mt. Hamilton and which serve the VNC desktops to the Lick remote observing sites can be configured to provide a resolution matched to the resolution of the monitors at the remote site that will be connected for the given night. In the case of observing teams that are split between multiple sites, the VNC servers are configured to a resolution that corresponds to the least common denominator of the the sites involved.

8.2 Observing teams distributed across multiple sites

As noted in Section 6.1, a growing number of Keck observations are now conducted by observing teams whose members are distributed between two or more external sites. While the existing VNC-based software easily supports this capability, some care needs to be taken in establishing the H.323-based video-conferencing connections between the various external sites in order to minimize audio and video latencies. While the video-conferencing systems at some of the external sites provide support for only point-to-point connections, many of the sites have systems that include an embedded multi-point controller capable of connecting four sites together in a multi-site video-conference. In general, connections should be made so that only a single trans-Pacific video-conference connection is established.

For example, in the case of a Keck observing team that is distributed between UCSD, UCLA, and CIT and where embedded multi-point controllers are available at UCLA and at WMKO, an optimal video-conferencing connection strategy would be for the UCSD and CIT sites to connect to the multi-point controller at UCLA, which would then in turn establish a connection to the multi-point controller at the WMKO headquarters in Waimea; the Keck observing assistant at the Mauna Kea summit would also establish a connection to the multi-point controller in Waimea. In this manner, any unnecessary routing of video-conferencing traffic across the Pacific is avoided and audio and video latencies are minimized.

To provide better coordination between such multi-site observing teams, we have developed software that monitors the connection and disconnection of the ssh-tunnels which convey the VNC protocol traffic between the external sites and the observatory site where the VNC servers are run. This software alerts users of a VNC desktop whenever another site either connects to or disconnects from that desktop, noting the connection and disconnection times. This enables observers in such teams to quickly determine which of their colleagues are currently connected to a given VNC desktop, as well as to determine when a colleague not currently connected was last connected. This software is in routine use at Lick and will be ported to Keck later this year.

8.3 Simultaneous observations

On at least one occasion, observations at Keck were monitored remotely from Mt. Hamilton by an observer who had been allocated observing time on the Shane 3-m at Lick on the same night that he also needed to supervise one of his graduate students who was in Waimea and observing on Keck II. Although this is not yet an officially-supported capability, this experiment demonstrated the ability of a UC-affiliated observer to coordinate observations being conducted locally at Mt. Hamilton with observations being carried out simultaneously with an instrument at Keck. In principle, the reverse should also be possible. Further study is needed to determine whether such capabilities should be made generally available.

Similarly, the existing remote observing software was recently employed to enable an observer at the Shane 3-m to remotely operate the Nickel 1-m so as to carry out simultaneous remote observations with both telescopes.

9. FUTURE PLANS

The Keck and Lick remote observing software that runs at the external sites is currently implemented as a set of scripts that are invoked from the command line. Work is underway to provide a graphic user interface (GUI) front-end to these scripts in order to make this software more user-friendly and reduce problems with remote observers making typing errors.

Until recently, at both Keck and Lick, on nights when observers were observing "at the observatory," instrument control and data acquisition software interfaces and displays were run within the context of the local desktops on the workstations at which the observers were seated. But on nights when the observers were working remotely from their home institutions, such software was run within the context of a shared VNC desktop. Shifting back and forth between these two different environments created unnecessary overhead for the support astronomers at each observatory, and also made for a less seamless transition for those observers who sometimes observe at the observatory and sometimes observe from their home institutions.

As a result, at Lick, instrument control and data acquisition software interfaces and displays for most instruments are now always run within the context of the VNC desktops, regardless of whether the observer is observing at the observatory or at his or her home institution. This provides a more consistent operating environment for both the observers and support astronomers. It also provides the added benefit of enabling the support astronomers (or other technical support staff located off-site) to provide more effective remote support if they are called at home in the middle on the night; in such cases, they are always able to connect to the shared VNC desktop to see exactly what the observer is seeing, regardless of that observer's location.

For similar reasons, WMKO is currently in the process of making a similar transition; shared VNC desktops will soon become the default environment in which instrument control and data acquisition interfaces and displays are run. An additional motivation to implement such "all-VNC-all-the-time" operation at WMKO is to allow the summit-based Observing Assistant to "watch" what the observer at the remote site is doing with the instrument and thereby be better able to assist with strategies and troubleshooting.

10. APPLICABILITY TO OTHER OBSERVATORIES

The solutions we have developed to support remote observing with the Keck and Lick telescopes are in principle readily adaptable to other observatories with similar instrument control interface designs, such as the planned Thirty Meter Telescope (TMT). Given the acceptance that this mode of observing has achieved at both Keck and Lick and assuming that fossil fuel prices continue to increase the cost of trans-oceanic travel, it is almost certain that observers will want to operate these new telescopes from remote sites starting at first light (and prior to that, engineers will debug instruments remotely during the commissioning phase). If the new generation of observatories is to make best use of their remote observing capability, the design work required to support this mode should be considered early in the project.

11. CONCLUSION

The effort to establish Keck "mainland-observing" facilities was an experiment that began over a decade ago. At that time, it was unclear whether such a mode of observing would prove reliable or whether it would be accepted by the Keck observing community. With a modest investment in hardware and software over the intervening years, that experiment has now been expanded successfully to include eleven external sites, and has spawned the corresponding implementation of remote observing at Lick; the resulting cumulative savings in travel costs and travel time have been substantial. The usage metrics presented here indicate that this mode of observing has earned significant acceptance within both the Keck and Lick observing communities. A number of factors contributed to the success of this experiment, but the most important were the decisions to avoid unnecessary complexity, and to construct the system using well-engineered and mature hardware and software components.

It is also clear that remote observing from the observer's home institution is not always the best solution for some observers and circumstances, and that observing "at the observatory" is an important option to maintain. In planning next-generation observatories such as the TMT, it is important to provide observers with the flexibility of choosing either observing mode, and to allocate sufficient resources during design and implementation to ensure that an optimum mix of observer support facilities is provided at the observatory as well as at the external sites.

ACKNOWLEDGMENTS

The network that makes all this possible has been developed over the past decade through partnerships involving universities and networking organizations in Hawaii, Australia, Washington and California with support from the National Science Foundation International Research Network Connections (IRNC) program and others. Keck Observatory is connected via the Mauna Kea Observatories Communication Network at the summit and other University of Hawaii connections on the Big Island of Hawaii. High speed connectivity from Hawaii takes place over submarine fiber provided by the Australian Academic and Research Network (AARNet) through the SX TransPORT project on the Southern Cross Cable Network, which also provides global connectivity to Australian universities and research facilities. The Corporation for Educational Networking Initiatives in California (CENIC) provides connectivity from the submarine fiber landing station in the U.S. to CENIC's California Research and Education Network (CalREN), which serves California's universities, colleges and K12 schools. Connectivity is further extended to the global research and education networking community through the Pacific Wave distributed international peering exchange in Los Angeles, Sunnyvale, and Seattle.

We also thank the following WMKO staff who contribute to the ongoing operation of the remote observing facilities in Waimea and in California: Randy Campbell, Jon Chock, Liz Chock, Al Conrad, Scott Dahm, Grant Hill, Marc Kassis, Jim Lyke, Jeff Mader, Julia Simmons, and Hien Tran; and the following UCO/Lick staff at Mt. Hamilton: Keith Baker, Kostas Chloros, Wayne Earthman, John Gates, Thomas Lowe, Kris Miller, John Morey, and Donnie Redel.

We also acknowledge the efforts of the following individuals for their efforts in setting up the various external remote observing sites: Judy Cohen and Patrick Shopbell (CIT); Deb Agarwal, Saul Perlmutter, Masaaki Yamato, and Tony Spadafora (LBNL); George Hau (Swinburne University); Andrew Howard, Kelley McDonald, and Geoff Marcy (UCB); Chris Fassnacht and Daniel Wang (UCD); Gary Channan, Aaron Barth, Tammy Smecker-Hane, and Carrollan Simmons (UCI); Matthew Barczys, Chris Johnson, Leon Kopelevich, Ian McClean, Laurie Liles, and Jason Weiss (UCLA); Bill Strossman, Gillian Wilson, and Gabriela Canalizo (UCR); Peter James, David Kirkman, John O'Meara, and David Tytler (UCSD); Glenn Schiferl, Tommaso Treu, and Crystal Martin (UCSB); Marc Boolootian, Jeff Mallory, and Jim Warner (UCSC).

The W. M. Keck Observatory is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation.

REFERENCES

[1] Kibrick, R., Conrad, A., and Perala, A., "Through the Far Looking Glass: Collaborative Remote observing With the W. M. Keck Observatory," *ACM Interactions* **5**(3), 32–39 (May-June 1998).

[2] Conrad, A. R., Kibrick, R., and Gathright, J., "Remote Observing with the Keck Telescopes," in [*Telescope Control Systems II*], Lewis, H., ed., *Proc. SPIE* **3112**, 99–110 (1997).

[3] Cohen, J., Shopbell, P., and Bergman, L., "Remote Observing with the Keck Telescope Using the ACTS Satellite," in [*Final Report for NASA Grant BK-509-20-42-00-00*], 1–22 (March 1, 1998).

[4] Kibrick, R. I., Allen, S. L., and Conrad, A. R., "Remote observing with the Keck Telescopes from the U.S mainland," in [*Advanced Global Communications Technologies for Astronomy*], Kibrick, R. and Wallander, A., eds., *Proc. SPIE* **4011**, 104–116 (2000).

[5] Kibrick, R. I., Hayes, B., Allen, S. L., and Conrad, A., "Remote observing with the Keck Telescopes from multiple sites in California," in [*Advanced Global Communications Technologies for Astronomy II*], Kibrick, R. I., ed., *Proc. SPIE* **4845**, 80–93 (2002).

[6] Wirth, G. D., Kibrick, R. I., Goodrich, R. W., and Lyke, J. E., "Operating a wide-area remote observing system for the W. M. Keck Observatory," in [*Observatory Operations: Strategies, Processes, and Systems*], Brissenden, R. J. and Silva, D. R., eds., *Proc. SPIE* **7016**, 70160Y (2008).

[7] Grigsby, B. J., Chloros, K., Gates, J., Deich, W. T., Gates, E. L., and Kibrick, R. I., "Remote observing with the Nickel Telescope at Lick Observatory," in [*Observatory Operations: Strategies, Processes, and Systems*], Brissenden, R. J. and Silva, D. R., eds., *Proc. SPIE* **7016**, 701627 (2008).

[8] Kibrick, R., Allen, S. L., Conrad, A., Stickel, T., and Wirth, G., "Optimizing the use of X and VNC protocols for support of remote observing," in [*Advanced Software, Control, and Communication Systems for Astronomy*], Lewis, H. and Raffi, G., eds., *Proc. SPIE* **5496**, 323–334 (2004).